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GEOLOGY AND DEVELOPMENT OF OKLAHOMA CITY FIELD OKLAHOMA COUNTY, OKLAHOMA[1]

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ABSTRACT

The Oklahoma City field, located near the geographical center of the state, is a large faulted anticline in the pre-Pennsylvanian rocks the structure of which is represented by anticlinal folding in the Pennsylvanian and Permian sediments. It was discovered by geological mapping on the Garber sandstone (a surface formation). The main reservoir rocks are massive magnesian limestone of Cambro-Ordovician age and sandstones in the Simpson group of Ordovician age. Oil is obtained at depths ranging from 6,100 to 6,500 feet under pressures of 2,300 pounds per square inch. The total estimated productive area is 12,800 acres, approximately 60 per cent of which has been developed. Fifty-thousand-barrel wells are not uncommon. Many records have been established for the drilling and completion of large wells. Folding and faulting of the pre-Pennsylvanian sediments occurred in late Mississippian or early Pennsylvanian.

INTRODUCTION

The Oklahoma City field, located in T. 10, 11, and 12 N., R. 2 and 3 W., Oklahoma County, Oklahoma, ranks among the major oil fields of the Mid-Continent region. The depth of the producing formations and the extremely large volumes of gas and oil encountered under high pressures have developed new technique in drilling and production methods. The discovery of the field purely on geological evidence and

[1]Read before the Association at the Oklahoma City meeting, March 24, 1932. Manuscript received, May, 1932. C. R. Hoyle, E. I. Thompson and Norval Ballard of the Phillips Petroleum Company and L. R. McFarland of the Indian Territory Illuminating Oil Company actively assisted in the preparation of the paper.

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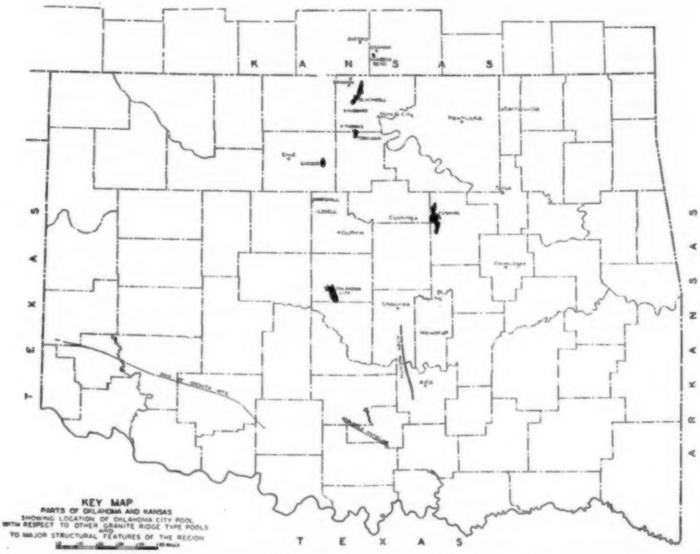

FIG. 1.—Key map, parts of Oklahoma and Kansas, showing location of Oklahoma City pool.

the unprecedented use of subsurface data in its development are outstanding features of the field from a geological standpoint.

The purpose of the writers is to give a relatively detailed account of the development together with a discussion of the geological and engineering problems involved. Access has been had to complete information on the topics discussed and the writers feel that the paper is an accurate description of the general conditions.

ACKNOWLEDGMENTS

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Other sources of information, both written and by personal communication, are duly acknowledged in the text.

HISTORY

Early work.—The early history of exploration and development in the vicinity of Oklahoma City was made the subject of a very careful investigation by A. Travis, whose account[1] the writers consider probably the most authentic. Travis states:[2]

> The two geologists who first observed a favorable oil structure near Oklahoma City were probably George D. Morgan and Jerry B. Newby. The exact dates when these first observations were made seem to have been lost. Morgan says, "In either 1917 or 1919, and I can not remember which year, I worked out the structure at Oklahoma City." Everett Carpenter, to whom Morgan referred me, says "I am of the opinion it was about 1917." Jerry B. Newby, who also worked out the structure, says, "My work north and northeast of Oklahoma City was done in the early part of 1919."

L. E. Trout, in the fall of 1919, made a reconnaissance of the area and "Late in 1920 or early in 1921,"[3] mapped an area in southern Oklahoma and northern Cleveland counties in what is now the southern part of the Oklahoma City field. This seems to have been the first structure map prepared of the region. With Trout were associated S. H. Woods, Claude Dalley, and L. R. Trout. In 1925 a well located by Trout in Sec. 36, T. 11 N., R. 3 W., near the Cleveland County line, was drilled to a depth of 4,480 feet. Several minor showings of oil were reported.

In 1925, John R. Bunn mapped a surface "high" north of the State Capitol, and a deep test (7,180 feet) drilled by Cromwell-Franklin,

[1]A. Travis, "Oil and Gas in Oklahoma—Oklahoma County," *Oklahoma Geol. Survey Bull. 40-SS* (May, 1930).

[2]*Op. cit.*, p. 6.

[3]A. Travis, *op. cit.*, p. 6.

Thompson No. 1, SE. ¼, NE. ¼, Sec. 15, T. 12 N., R. 3 W., found water in the "Wilcox." This well had several minor showings in shallower horizons. An earlier well drilled not far away is the discovery well of Oklahoma County.

Thus the presence of an anticline lying north, northeast, and southeast of Oklahoma City has been a matter of general geologic knowledge for several years, and several geologists not mentioned herewith have at various times noted the "high."

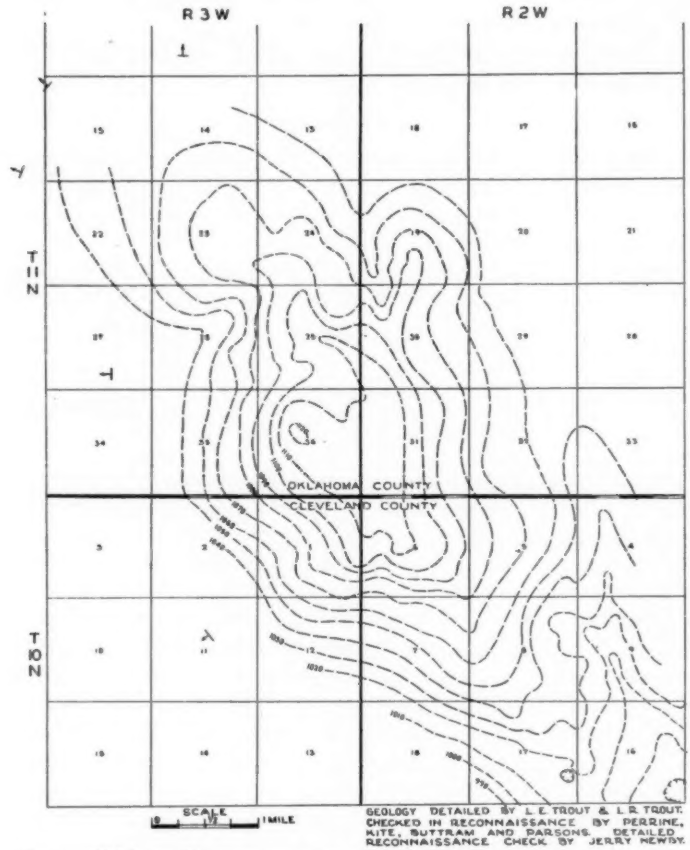

FIG. 2.—Oklahoma City structure, as mapped by L. E. and L. R. Trout in 1920-21.

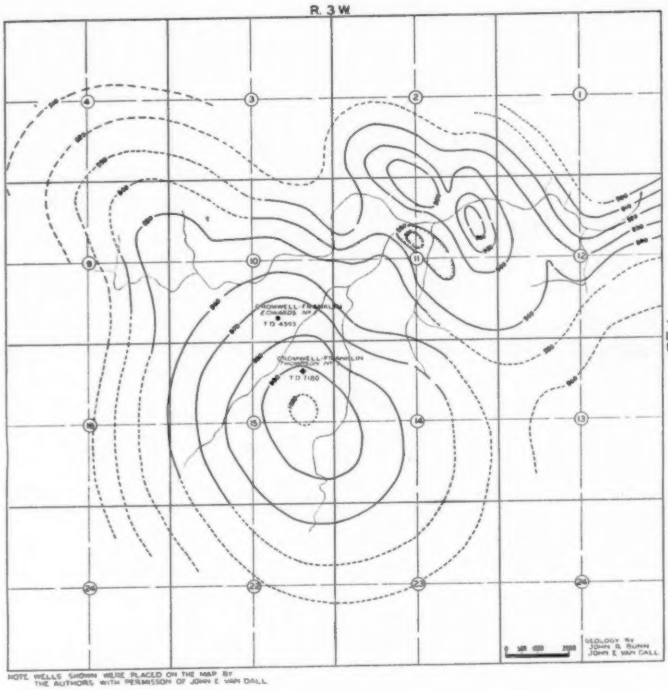

FIG. 3.—Surface structural map of part of T. 12 N., R. 3 W., Oklahoma County, Oklahoma. Prepared by John R. Bunn and John E. Van Dall in 1925.

In 1927, G. E. Anderson, working independently while doing reconnaissance work for the Indian Territory Illuminating Oil Company, reported a southward projecting nose running through Oklahoma City. He outlined this nose on the Garber-Hennessey contact. Following Anderson's report, the detailed geology of T. 10-12 N., R. 2 and 3 W., was structurally mapped for the geological department of the Indian Territory Illuminating Oil Company in February, 1928, by C. L. Wagner, under the supervision of J. H. Derden and C. W. Roop, and this work was approved by R. J. Riggs, chief geologist.

The Indian Territory Illuminating Oil Company then blocked approximately 10,000 acres on this structure. A location was made in the

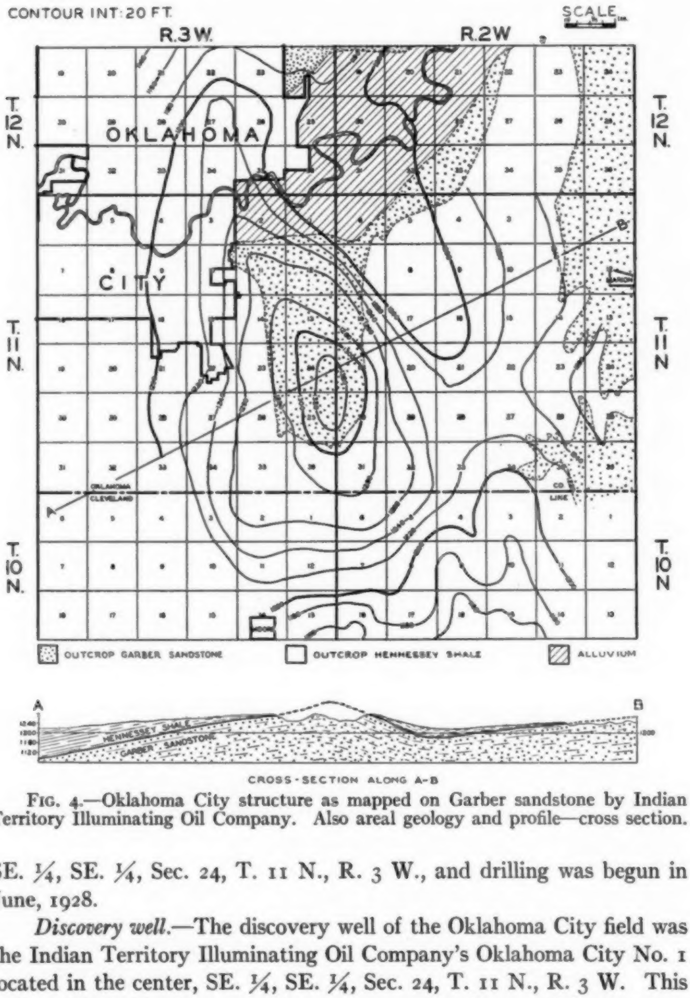

FIG. 4.—Oklahoma City structure as mapped on Garber sandstone by Indian Territory Illuminating Oil Company. Also areal geology and profile—cross section.

SE. ¼, SE. ¼, Sec. 24, T. 11 N., R. 3 W., and drilling was begun in June, 1928.

Discovery well.—The discovery well of the Oklahoma City field was the Indian Territory Illuminating Oil Company's Oklahoma City No. 1 located in the center, SE. ¼, SE. ¼, Sec. 24, T. 11 N., R. 3 W. This well was drilled in the center of a 40-acre tract at the top of the structure as mapped on the Garber sandstone. Drilling operations were commenced on June 12, 1928. Rotary drilling equipment was used, and information obtained from examination of the drill cuttings was supplemented by

cores taken at frequent intervals and by drill-stem tests whenever favorable showings of oil or gas were found.

Several minor showings of oil and gas were reported in the upper part of the Pennsylvanian, and a drill-stem test of a sand encountered from 3,996 to 4,012 feet showed an estimated gas volume of 25,000,000 cubic feet. Drill-stem tests were made at several points below this with only moderate success, due in part to failure of the tester to operate properly at these greater depths.

Nine-inch casing was cemented at 4,782 feet, and when drilling operations were resumed a core taken between 4,797 feet and 4,816 feet contained a strong showing of gas. The well blew in unexpectedly while drill pipe was being run in the hole to take another core. The gas volume gauged 47,721,000 cubic feet with no oil. Tests made of the gas showed a gravity of 0.787 and a gasoline content of 0.06 gallon per thousand cubic feet. Shut-in pressure was 1,720 pounds per square inch. The well was brought under control and drilling continued after a short delay. Cores taken in the lower part of this sand body showed a relatively porous sand which had every indication of being thoroughly oil saturated. However, subsequent production tests proved very disappointing, as no commercial oil production has been developed from this horizon.

On November 3, 1928, at a depth of 6,165 feet, the well encountered a banded gray and brown dolomite, the identity of which was in considerable doubt. Slight showings of oil were reported in cores, and after reaching a depth of 6,402 feet still in the same formation, the 7-inch casing was cemented at 6,355 feet. The cement plug was drilled out with cable tools on November 30, 1928, and the gas pressure below the plug blew the tools up the hole where the line parted and the tools bridged in the hole at a depth of 2,500 feet. After some efforts had been made to remove the tools, they were blown from the hole on the afternoon of December 4, 1928, and the well was completed as a gusher with an initial gauge of 2,895 barrels of oil in 14 hours. Tests showed the gravity of the oil to be 39° Bé. at a temperature of 70° F. Initial gas volume was 6,500,000 cubic feet, with a gasoline content of 1.38 gallons per thousand.

The well was deepened 3 feet, from 6,402 to 6,405 feet, on December 14, 1928, where it attained its maximum rate of production of 6,564 barrels in 24 hours.

Geologists and paleontologists of interested companies were in doubt about the age of the producing formation, due largely to a re-

luctance to accept the correlation indicated by the characteristics of the formation because of the magnitude of the structure which would be indicated by correlation of this horizon as Arbuckle, or "Siliceous lime." The consensus of opinion, however, favored such a correlation and further drilling shortly proved this to be correct.

On January 1, 1929, the discovery well had been deepened with cable tools to a depth of 6,498 feet and was producing approximately 5,600 barrels per day by natural flow. The well was put on gas lift March 3, 1929, at which time it was still flowing naturally and had produced 456,599 barrels of oil. The first appearance of water was on March 4, 1929, three months after completion, when the well showed 0.5 per cent free water and 5 per cent emulsion. The accumulated production at the time of first water appearance was 456,724 barrels.

On September 13, 1929, the well was shut in to conform to an operators' agreement for a 30-day shut-down of producing wells in the Oklahoma City field. The accumulated oil production of the well at this time was 932,946 barrels.

During the early part of November, 1929, the well was deepened to its final depth of 6,624 feet with no appreciable increase in production.

On July 31, 1931, the well was plugged back and re-completed as an 80,000,000 cubic-foot gas well in the "Layton" sandstone at 4,790-4,820 feet after producing 1,002,887 barrels of oil from the Arbuckle limestone.

SURFACE FORMATIONS

The Hennessey shale and Garber sandstone of the Enid group, lower Permian, are the outcropping formations of the anticline with the exception of an area in the North Canadian River valley which is alluvium covered. The areal distribution of the surface beds is shown on Figure 4.

SUBSURFACE FORMATIONS

The nomenclature used by the writers is that adopted during the early development of the field, when the identity of the various markers was in considerable doubt. Common usage and the fact that the correlation of many of the formations is still in question, make it impracticable to attempt a thorough discussion of correlations in a paper of this kind.

Wells at Oklahoma City penetrate approximately 2,000 feet of lower Permian and 4,000 feet of Pennsylvanian sediments before reaching the Ordovician producing horizons. With the exception of the Ordovician

beds, present on the flanks of the anticline, the subsurface horizons are comparatively easy of correlation because of the prominence and regularity of occurrence of several persistent key beds.

Although the field has been completely developed by the rotary drilling method, details of the stratigraphy are well known due to the fact that samples of drill cuttings were carefully saved on nearly every well drilled in the field. All maps, correlations, and descriptions in this paper are based on microscopic study of these cuttings.

The subsurface formations are discussed in the order in which they are penetrated by the drill. Figure 5 shows in columnar section a composite log of the Permian-Pennsylvanian rocks encountered below the surface. This section is based on averages taken from several hundred wells distributed throughout the field.

PERMIAN

The Permian in the Oklahoma City field belongs in the Enid group.[1] It has been subdivided as follows.

Hennessey shale.—Most of the wells in the field begin in the basal part of the Hennessey shale. This shale, which is red, more or less sandy, clay shale, ranges from almost nothing to 120 feet in thickness, with an average of about 60 feet for the field as a whole.

"Garber" sandstone.—The "Garber" sandstone, which underlies the Hennessey shale, has a thickness of about 750 feet. It is a series of massive fine-grained sandstones separated by 10-30-foot beds of red clay shales. As shown in Figure 4, the Garber sandstone is exposed along the crest of the fold. The Garber sands contain large quantities of fresh water and have supplied, from shallow wells, a part of the water used in developing the field.

"Wellington" formation.—Beneath the "Garber" sandstone are about 700 feet of bright red-to-drab clay shales, with red, fine-grained, loosely bonded sands in the upper part, and thin nodular limestones in the basal part. These sands and shales belong in the "Wellington" formation of the Enid group.

"Stillwater" formation.—Below the "Wellington" is the "Stillwater" formation, with a thickness of about 750 feet. At this point in the section, the shales change from bright red to dark brown. This change in color is marked, easily recognized, and persistent in the entire area. Thin nodular limestone beds are present in the brown shales at the top of the "Stillwater." The basal 300-350 feet consists of alternating gray

[1] F. L. Aurin, H. G. Officer, and Charles N. Gould, "The Subdivision of the Enid Formation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 8 (August, 1926), pp. 786-99.

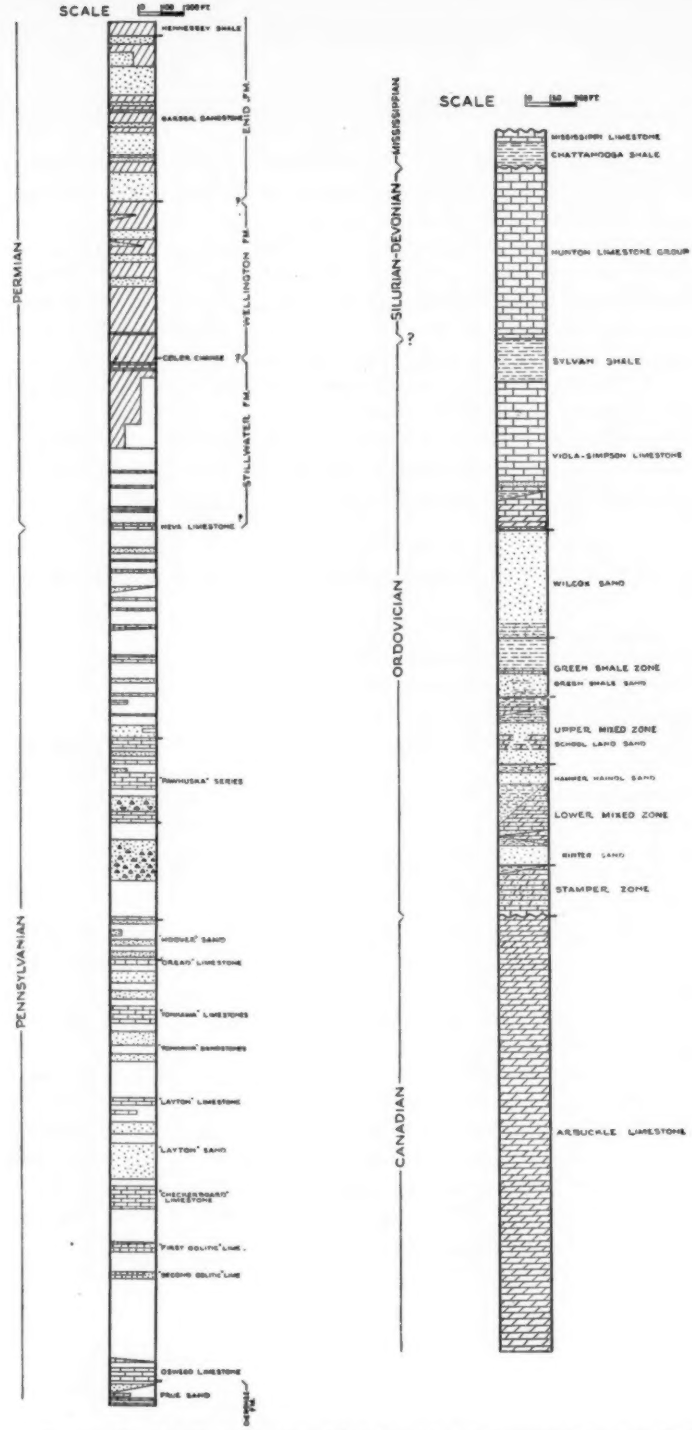

FIG. 5.—Permian-Pennsylvanian (at left) and pre-Pennsylvanian (at right) columnar sections, Oklahoma City field. Based on averages taken from several hundred wells.

and brown soft shales with thin, white, fine-grained, tightly bonded sandstones, and thin, gray, finely crystalline marine limestones. The "Neva" limestone, a 10-30-foot bed of gray, finely crystalline limestone, marks the base of the "Stillwater." The average depth to the "Neva" as shown on the column is 2,250 feet. The "Neva" is not only a persistent bed in the field itself, but is readily recognizable in most of the wells drilled in the surrounding area.

PENNSYLVANIAN

"*Pawhuska*" *series.*—From the base of the "Neva" to the top of the "Pawhuska" series is 930 feet of gray and brown bedded shale, with numerous poorly developed, gray-to-white, finely crystalline limestones, and white, fine-grained, tight sands. These sands and limestones can not be traced in wells continuously throughout large areas, but seemingly are lenticular. This apparent discontinuity of the beds is probably due to inability to take samples of the rotary cuttings accurately enough to determine their exact position in every well. This part of the section is usually drilled rapidly. A large part of the Wabaunsee group is represented in this 930 feet of section.

"Pawhuska" is the field name for a very prominent and persistent series of beds that occur at approximately 3,200 feet. The "Pawhuska" consists of three massive, white to gray, finely crystalline limestones, separated by beds of shale and coarse-to-fine sandstones. The upper of the three limestones is about 30 feet in average thickness and is separated from the middle limestone by an interval of 110 feet. This interval is largely composed of gray bedded shale with a 20-foot sand near the top and thin limestone and sandstone stringers in the basal part. The middle limestone is the most massive, has a thickness of 70 feet, and is separated from the lower limestone by 100 feet of section. The top 30 feet of this section consists of bedded gray shale, and the lower 70 feet, medium to coarse-grained, angular sand with white, angular chert fragments. The lower limestone has a thickness of 45 feet. About 60 feet of gray bedded shale separates this limestone from a sand and chert conglomerate, which has a very characteristic lithology.

"*Hoover*" *sandstone.*—Beneath the cherty sandstone at the base of the "Pawhuska" series, is 350 feet of gray bedded shales, with a thin limestone, 10-20 feet thick, near the middle, and interbedded sandstones in the lower 150 feet. These sandstones, which contain oil and gas in wells drilled well up on the anticline, have been tested in a few wells with the results described under oil and gas horizons.

"Oread" limestone.—The "Oread" limestone is the field name for the next prominent marker below the "Pawhuska." The "Oread" is a 20-foot white-to-buff, finely crystalline limestone occurring at an average depth of 4,090 feet. Between the "Oread" limestone and the "Tonkawa" limestone, 160 feet below, there are coarse massive sandstones separated by thin beds of gray soft shale. These sandstones, which have been tested for oil and gas, are discussed under Pennsylvanian oil and gas horizons.

"Tonkawa" limestones and sandstones.—"Tonkawa" is the field name for the first key bed below the "Oread." The "Tonkawa" ordinarily occurs as two 30-40-foot, gray-to-buff, finely crystalline limestones separated by 10-20 feet of gray, in places sandy, shale.

Below the "Tonkawa" limestones is 350 feet of shale and sand which separate the "Tonkawa" from the next prominent bed below, the "Layton" limestone. Fifty feet from the base of the "Lower Tonkawa" limestone is the first of two massive sands, each 40-60 feet in thickness, which are separated by 30 feet of gray, soft shale. Though these sands have not been tested, they are thought to be water-bearing.

"Layton" limestone and "Layton" sandstone.—The "Layton" limestone is a series of alternating thin, gray to buff limestones and gray shales approximately 4,820 feet in depth. The thickness of the limestones in this series is highly variable, ranging from a few feet to as much as 100 feet.

Below the "Layton" limestone is the "Layton" sandstone, which is the most prominent sandstone in the Pennsylvanian section. The "Layton" sandstone ordinarily consists of an upper and a lower sand body separated by about 40 feet of gray shale. The upper sand has a thickness of 50 feet. The lower is a massive sand 160 feet in thickness. The sand is coarse-grained and angular, ranging from loosely bonded to very tightly cemented, with crystals of secondary quartz on the larger sand grains.

The upper sand in the "Layton" has been tested and found to be a very prolific gas horizon. It is producing gas in several wells in the field as described under Pennsylvanian oil and gas horizons.

"Checkerboard" limestone.—The "Checkerboard," which is a massive, gray-to-white finely crystalline limestone, is the most reliable bed for structure mapping in the Pennsylvanian, because of its thickness (100 feet) and its regularity of occurrence. It is easily and generally recognized, even by drilling crews.

"*Oölitic*" *limestones.*—From the base of the "Checkerboard" limestone to the top of the "Oswego" limestone is 670 feet of shale with two oölitic sandy limestones, or calcareous sands in the upper part. The 150 feet of shale which underlies and separates the "Checkerboard" from the "First Oölitic" limestone is dark gray-to-black fine-textured shale. The upper of the two "Oölitic" limestones, known in the field as the "First Oölitic," is a sandy, gray-to-buff, finely crystalline limestone with large, white-to-gray, oölitic inclusions. In places it contains some nodular glauconite. Resting on the "First Oölitic" and here and there replacing it completely in the section, is a medium sized, subangular, porous to tightly lime-cemented sand which varies in thickness from a trace to 80 feet, the average thickness being about 10 feet. Ninety feet below the "First Oölitic" is the "Second Oölitic," a 30-foot, finely crystalline, very sandy limestone, with white oölitic inclusions.

From the "Second Oölitic" to the "Oswego" limestone is a section of 360 feet of gray, finely micaceous shale which is unbroken except for local sandy streaks.

The "Oölitic" limestones and the sandstones associated with them produce both oil and gas.

"*Oswego*" *limestone.*—The "Oswego" limestone consists of two members, an upper thin member that ranges in thickness from almost nothing to 15 feet and a lower massive member whose average thickness is 60 feet. The upper and lower members are separated, where both are present, by about 20 feet of gray shale. The "Oswego" is gray and white, finely-to-coarsely crystalline limestone, generally very fossiliferous in the basal part. The basal part of the lower member is commonly honeycombed with small solution cavities and contains gas. The "Oswego" is highly variable in thickness on the anticline. In one well in Sec. 32, T. 11 N., R. 2 W., at the south end of the field, it was entirely absent, and in several other wells in the same area, very thin. In the north end of the field the "Oswego" has its maximum development, which is 150 feet.

"*Cherokee*" *formation.*—As an average for the field it is 100 feet from the base of the "Oswego" limestone to the base of the Pennsylvanian system. This 100 feet of section, probably Cherokee in age, is variable in different parts of the field. It ordinarily consists of gray, finely micaceous shales, brown, micaceous, fine-grained sands, and thin gray, coarsely-to-finely crystalline limestones. In places brown micaceous sandstone (Prue) continues, in unbroken section, from just below the "Oswego" limestone to the base of the Pennsylvanian. In a few

wells in Sec. 15, T. 11 N., R. 3 W., a 30-40-foot limestone is present nearly midway between the base of the "Oswego" and the base of the Pennsylvanian. Where this limestone is present, brown, micaceous sandstone occurs above and below it. The section from the top of the "Oswego" limestone to the base of the Pennsylvanian system is remarkably uniform in thickness throughout the field, although it does show some shortening in a few wells on the crest of the anticline. Structure maps drawn on the base of the Pennsylvanian system show accurately the Pennsylvanian structure. The "Prue" sandstone contains both oil and gas.

"*Unconformity sand.*"—On the downthrown side of the fault, 20-40 feet of erosional or detrital material, largely sand, occurs at the base of the Pennsylvanian, lying on the pre-Pennsylvanian rocks. The sand, which is coarse angular to subrounded, contains fragments of the pre-Pennsylvanian sediments. This erosional sandstone produces small amounts of oil.

PRE-PENNSYLVANIAN

The post-Mississippian truncation removed the formations from "Mississippi lime," to and including the Viola limestone, from the producing part of the anticline. However, several wells drilled on the downthrown side of the fault, in the course of defining the field, encountered a normal section of pre-Pennsylvanian rocks (Fig. 5). As a study of the pre-Pennsylvanian rocks above the Bromide member of the Simpson group has been limited, because of the few wells that have encountered them, the discussion of this part of the section is somewhat general.

"*Mississippi lime.*"—The "Mississippi lime" has been encountered in three wells drilled on the east or down-faulted side of the anticline. The limestone is brown-to-gray, finely crystalline, sugary in texture, with disseminated, nodular glauconite, and thin partings of greenish gray shale. The average thickness is 25 feet. In the area adjoining the field on the east and north the "Mississippi lime" is absent, Chattanooga shale or Hunton limestone being encountered below the Pennsylvanian.

Chattanooga shale.—The Chattanooga shale, present in the three wells that encountered the "Mississippi lime," is the ordinary dark brown, bituminous shale with nodules of black or brown chert and glauconite. As in other areas it is characterized by large numbers of *Sporangitis huronense.* Its average thickness is 50 feet. It apparently is conformable with the "Mississippi lime" above.

Hunton limestone group.—The Hunton limestone group has been encountered in five wells drilled on the downthrown side of the fault. It is present in complete section in only three of the five wells. The full section of Hunton limestone is 350 feet in thickness. The upper 100 feet of the limestone is coarsely crystalline and white with here and there pink crystals. Disseminated glauconite and gray translucent chert inclusions are plentiful. Below the coarsely crystalline limestone is 85 feet of gray-to-tan finely crystalline, greenish gray marly limestone. The remainder of the section is white and pink coarsely crystalline limestone with thin beds of gray-to-greenish gray finely crystalline platy limestone. No attempt has been made to subdivide the Hunton group, although it is thought that the Bois d'Arc, Harrigan, Henryhouse, and Chimneyhill members are all represented in the section.

The Hunton contained oil showings in wells drilled in the area immediately surrounding the field, but no production has been developed. There is no marked evidence of unconformity with the Chattanooga shale above.

Sylvan shale.—The Sylvan shale was encountered in the same five wells that penetrated the Hunton limestone. It is grayish green, fine-textured, splintery shale, with finely disseminated pyrite. The average thickness is 85 feet.

Viola-Simpson limestone.—No attempt has been made in this paper to divide the 300 feet of limestones and dolomites found below the Sylvan shale and above the "Wilcox sand," into the Viola limestone and the Bromide and Tulip Creek members of the Simpson group. Wells producing from the "Wilcox sand" have encountered in some places a few feet and in other places as much as 210 feet of limestone and dolomite above the sandstone.

It is thought that no well producing from the "Wilcox sand" has penetrated beds higher stratigraphically than the Bromide member of the Simpson group. The Viola is present, however, in five wells drilled on the downthrown side of the fault. Because of inability to make a satisfactory division, the section encountered in these wells is described and used as a unit in this paper. Below this point the Simpson group has been divided into several units, the division being made on the basis of lithology and convenience in field use. The upper part of the Viola-Simpson is composed of gray and white coarsely crystalline limestones with pink crystals and nodular glauconite. A 20-foot bed of white, hard, dense, platy limestone occurs 30-40 feet below the top. Below this bed are intercalated dense, platy limestones and brown and gray, sugary

dolomites, with a few thin beds of coarsely crystalline, gray and white dolomite with sandy streaks and gray chert zones here and there. Approximately 100 feet above the top of the "Wilcox sand" a 5-10-foot zone of loose to almost quartzitic sand, or sandy dolomite with large, rounded, frosted sand grains, occurs. Between this sandy zone and the "Wilcox sand" below, are interbedded thin light green, fine-textured shales, limestones, and dolomites. The basal 15-20 feet of this section is ordinarily brown, sugary, very sandy dolomite. The sand grains in this zone are very large (maximum, 1.6 millimeters), rounded, and frosted. This sandy dolomite grades into the "Wilcox sand" below.

The sandy dolomite immediately above the "Wilcox sand" is producing small quantities of oil in three wells, low structurally, that were plugged back after testing "Wilcox sand."

"*Wilcox sand.*"—The "Wilcox sand" has an average thickness where present in the complete section of 220 feet. The upper 20-30 feet of the sandstone has very large, well rounded, pitted grains, intermixed in a matrix of subrounded grains of medium size. The large grains are present in largest percentage at the very top of the sandstone and in the limestone and dolomite immediately above. Where the top of the "Wilcox sand" is eroded, green shale and asphaltic inclusions are commonly present in the upper part of the sandstone remaining. From the coarse sandstone to within 5-20 feet of the base, the sandstone is remarkably well assorted and free from impurities. The grains are medium in size, subrounded, smooth, and loosely bonded. The basal 5-20 feet of the sandstone has thin partings of sandy, grass-green shale. The sandstone between the partings varies from white, tightly lime-cemented, to loose, highly porous sand. Thin partings of pale green, pyritic bentonite-like shale have been noted in several wells. These partings do not seem to occur at any particular point in the sand body. There are two or three places where zones 30-40 feet in thickness have been tightly cemented by dolomite or lime.

The "Wilcox sand" is the most prolific oil- and gas-producing horizon in the Oklahoma City field.

"*Green Shale*" *zone.*—Below the "Wilcox sand" is the "Green Shale" zone which averages 120 feet in thickness. At the top of the "Green Shale" zone is 60-70 feet of greenish, black-to-dark green, fine-textured, splintery shale. This shale is characterized by well defined bedding planes and the absence of sand grains or sandy phases. In places a 10-15-foot sandy dolomite is found near the middle of the shale section. At the base of the green shale is 10-20 feet of tan-to-gray, very

finely crystalline, granular dolomite with very large, rounded, pitted sand grains.

At the base of the "Green Shale" zone is the "Green Shale" sandstone, about 50 feet thick, which is very irregular both in composition and thickness. The sand grains range from coarse to medium in size, rounded to subrounded. Locally the sand may be loosely bonded and porous, dolomite cemented, or have numerous sandy, light green shale partings. It commonly contains small black shale and chert inclusions. In many places the top of the sandstone is a gradational phase from the sandy dolomite above. The "Green Shale" sandstone contains oil and gas, but is the least prolific of the Simpson sandstones.

"Upper Mixed" zone.—The "Upper Mixed" zone has an average thickness of 135 feet. At the top of this zone is 50 feet of interbedded, sandy, light green blocky shale and gray and white crystalline dolomites. Locally, sandy phases in this zone become thin lenticular sandstones. The sand grains which are distributed throughout the beds in this 50 feet of section are rounded to subrounded, medium in size, smooth and clear. In some parts of the field, a gray-to-tan finely crystalline, granular, sandy dolomite with large included sand grains is found near the middle of the zone. Maroon shales have been noted in this zone in several wells in the field.

Below this shaly zone and at the base of the "Upper Mixed" zone is the "School Land" sandstone. It has an average thickness of 85 feet. The top 30 feet of the "School Land" is a fine, well assorted, angular sand, tan in color excepting that it is pale greenish gray where irregularly dolomite cemented. Below this 30 feet of sandstone is 25 feet of fine, very uniformly sized, tightly dolomite-cemented sand. This zone varies from a very fine, pale green, dolomitic sand to sandy dolomite. Locally, sandy green shale occurs at this point in the section. The basal 30 feet of the "School Land" sandstone is a medium, uniformly sized, tan-to-buff angular sand with thin, irregular, gray, dolomite-cemented zones. This part of the "School Land" sandstone is often called the "Mollman sand." The "School Land" sandstone has a few small black inclusions. It produces both oil and gas, but is predominantly a gas sand in structurally high wells.

"Lower Mixed" zone.—The "Lower Mixed" zone has an average thickness, in the field, of 200 feet. It is a more or less heterogeneous zone composed of sands, shales, and dolomites. At the top of the "Lower Mixed" zone is 20 feet of dark green, fine-textured blocky shale which locally is entirely absent or replaced in the section by sandy gray and

white crystalline dolomites. In wells in which this shale is absent the "School Land" sandstone is in contact with the underlying "Hammer-Haindl" sandstone.

Below this 20-foot shale bed is very coarse sandstone, poorly assorted and partly lime-cemented. In the north part of the field this sandstone is composed of very large angular grains with secondary crystal growths, and well rounded grains in a fine-grained dolomitic matrix, the upper part of the bed being the coarsest. In the south part of the field, the sandstone has a larger percentage of well rounded grains and is better assorted. This coarse sandstone is locally known as the "Hammer-Haindl." Its physical characteristics are among the most constant features of the Simpson section. It varies in thickness from 10 to 50 feet with an average of 25 feet. The "Hammer-Haindl" sandstone is an oil- and gas-bearing horizon.

Below the "Hammer-Haindl" sandstone is 70 feet of intermixed and undifferentiated lenticular sandy gray and white dolomites with intercalated sandy, light and dark green unctuous, splintery-to-blocky shales with local development of the more sandy phases into thin lenticular sandstones.

At the base of the 70-foot intermixed zone is a coarsely crystalline gray and white dolomitic, fossiliferous limestone 10-20 feet in thickness which is persistent in most of the field. Between this bed and the "Kinter" sandstone which marks the base of the "Lower Mixed" zone, is 50 feet of intermixed finely crystalline gray and white sandy dolomites and dark and light green sandy shales. In the north end of the field, a characteristic, very sandy light green shale with large, rounded frosted grains lies on top of the Kinter sandstone. Locally, this sandy shale becomes a coarse poorly assorted sand with many very large well rounded and frosted grains. An occurrence or two of maroon shales have been noted in this part of the section.

At the base of the "Lower Mixed" zone is the Kinter sandstone which is variously known as the "Olds," "Johnson," "Lowery," and "Hoopes." The "Kinter" sandstone, which next to the "Wilcox" is the most prolific oil- and gas-producing horizon in the field, ranges in thickness from 20 to 80 feet, the average being about 40 feet. The sand is poorly assorted at the top, large, rounded frosted grains being included in a matrix of medium, subangular-to-subrounded, smooth grains. The lower part of the sandstone is relatively free from large sand grains and is more uniform in size. Thin, dolomitic, tightly cemented zones are irregularly present from the top to the bottom. The basal

part of the sandstone grades into the sandy dolomite below without a marked break.

"Stamper" zone.—The "Stamper" zone has an average thickness in the field of 110 feet. At the top of the zone, immediately below the Kinter sandstone, is light gray to buff, very finely crystalline, sucrose, sandy dolomite which ranges in thickness from 40 to 100 feet, with an average of 90 feet. Large, well rounded, frosted sand grains are distributed uniformly throughout the sugary dolomite. Near the top of the zone, beds of dark green fine-textured, sandy shales are present in many places, especially in the south part of the field. In places, clear, coarse-grained, subangular, porous, unassorted sand, 5-10 feet thick, occurs from 20 to 40 feet below the top of the zone. In this zone, about 50 feet above the underlying Arbuckle limestone, is a graptolite horizon. This graptolite has been identified by Charles E. Decker[1] as *Didymograptus artus*, which has a limited vertical range and is definitely known to be in the lower part of the Joins formation, where it has been found in a narrow zone.[2] Below the sandy dolomite, at the base of the "Stamper" zone, is the "Stamper" limestone. The "Stamper" limestone is highly variable in thickness, being entirely absent in parts of the field and as much as 40 feet thick in others. The average thickness is about 20 feet. The "Stamper" is gray and white, mottled, coarsely crystalline, soft-to-hard limestone which in places is partly or completely dolomitic. Among ostracods found in this limestone, Reginald W. Harris[3] has identified *Leperditella cooperi* n. sp. and *Leperditella brookingi* n. sp., diagnostic forms in the Joins formation, basal Simpson.

Arbuckle limestone.—The thickness of the Arbuckle limestone in the field is unknown, as no well has drilled through it. It has been penetrated 876 feet. The upper 200-250 feet of the Arbuckle limestone present in the field is gray to buff, very finely crystalline, sugary magnesian limestone with a few nodules of gray translucent chert, very thin partings of laminated, waxy, grayish green shale, and thin beds of white oölitic dolomitic limestone. At the top of this zone where it is normally in contact with the overlying "Stamper" limestone, basal Simpson, cores taken in wells have shown a brecciated zone with large angular fragments of dolomite in a dolomitic, silty matrix. Thin streaks of fine-to-large, rounded-to-subangular, smooth sand are irregularly present

[1]University of Oklahoma, Norman; personal communication.

[2]Charles E. Decker and Clifford A. Merritt, "The Stratigraphy and Physical Characteristics of the Simpson Group," *Oklahoma Geol. Survey Bull. 55* (1931), p. 14

[3]University of Oklahoma, Norman; personal communication.

in this upper section. Below the fine sugary dolomite are irregular zones of medium-to-coarsely crystalline dolomite, honeycombed with solution cavities. Many of the solution cavities are large enough to permit the forming of drusy surfaces by secondary crystallization of dolomite. The very porous zones alternate irregularly with zones of coarsely crystalline dolomite and a few white, coarsely-to-finely crystalline thin dolomitic limestones. Finely disseminated glauconite occurs throughout the section with white-to-gray translucent oölitic chert. Fluorite crystals have been found in several wells in the honeycombed porous zones. At places in the southeast part of the field, the Simpson-Arbuckle contact is apparently more or less gradational, both the Arbuckle and "Stamper" limestones being finely crystalline dolomite. The oil and gas production in the Arbuckle limestone is largely confined to porous zones below the upper 200-250 feet of sugary dolomite.

It is the opinion of the writers, based on rather fragmentary evidence, that the Arbuckle limestone encountered at Oklahoma City probably represents the upper part of the Arbuckle section as described by Decker.[1] This assumption is based largely on the presence of the gastropod *Hormotoma* in a core taken near the top of the Arbuckle in the Mid-Kansas Oil and Gas Company's Fortson No. 1, Sec. 24, T. 11 N., R. 3 W. Some work has been done on insoluble residues from samples of the Arbuckle at Oklahoma City,[2] the results of which are not definitely known to the writers.

STRUCTURE

The Oklahoma City field lies somewhat east of the alignment of Granite ridge "structures" which include El Dorado, Oxford, Blackwell, Garber, and Marshall. Although apparently not aligned with them, it has a close resemblance to typical Granite ridge structure. Though most Granite ridge structures have a north and south or a northeast and southwest trend, the Oklahoma City field trends northwest and southeast. This northwest and southeast trend possibly can be attributed to a swing in the Granite ridge line of folding as it enters the province of the northwest-southeast folds associated with the Wichita mountain system which was undergoing a major adjustment at approximately the same time.

The oil in the Oklahoma City field is found in a pronounced, faulted anticlinal fold. The history of the structure is related to at least five

[1]Charles E. Decker and Clifford A. Merritt, *Oklahoma Geol. Survey Cir. 15* (1928).

[2]H. S. McQueen, "Insoluble Residues as a Guide in Stratigraphic Studies," *Missouri Bur. Geol. and Mines* (1931)

periods of structural adjustment, with intervening periods of complete or partial submergence and more or less continuous deposition. They are: (1) post-Arbuckle-pre-Simpson, (2) post-Hunton-pre-Chattanooga, (3) late Mississippian or early Pennsylvanian, (4) Pennsylvanian, and (5) Permian or post-Permian.

Following a period of deposition extending from Upper Cambrian into Lower Ordovician during which the Arbuckle limestone was deposited, there was a slight regional warping and partial emergence. In the Oklahoma City area, there is no evidence of a marked hiatus at the close of Arbuckle time. No break of importance has been recognized between the conglomerate-breccia at the top of the Arbuckle limestone, and the limestones and dolomites of the Joins formation, at the base of the overlying Simpson group.

Following Arbuckle deposition, there was a period of shallow but apparently complete submergence during which the Simpson group from Joins to Bromide, the Viola limestone, the Sylvan shale, and the Hunton limestone were deposited (Lower Ordovician to late Devonian). At several places in this section, the character of the sediments indicates that there may have been partial emergence of the land mass, with attendant minor disconformities either through erosion or non-deposition, but there is no evidence of a marked break in sedimentation.

At the end of Hunton time there was a general emergence of the land mass in the northeastern and north-central parts of Oklahoma with subsequent erosion, which beveled off the beds in the northeastern part of the state down to the Arbuckle limestone, and exposed the beds above in concentric bands around this central core. The Oklahoma City area, although probably elevated during this period, did not undergo a great amount of erosion, since the Hunton limestone, when overlain by the Chattanooga shale, is present in full section.

Following the post-Hunton emergence, there was a relatively thin body of sediments deposited before the next uplift. During this time the Mississippian beds, Chattanooga shale, and "Mississippi lime" were deposited. The total thickness of Mississippian beds deposited over the anticline, as indicated by the thickness of these beds encountered on the down-faulted side, is probably not in excess of 100 feet. Wells drilled in the area immediately surrounding the field have not encountered Mississippian beds of greater thickness than 100 feet and in several places much less. This thin Mississippian section indicates that the area in and around the field was a relatively high area during most of Mississippian time.

The structural adjustments that were the principal factors in the formation of the Oklahoma City structure occurred either in late Mississippian or early Pennsylvanian time. After the deposition of the "Mississippi lime," the area now comprising the Oklahoma City field was folded into an anticline, faulted, and truncated, all three processes occurring more or less contemporaneously.

The fault which terminates the anticline on the east had its inception before the structure had been elevated a sufficient length of time for erosion to remove an appreciable amount of material from the crest or upthrown side, as the "Mississippi lime" is present in full thickness on the downthrown side of the fault in Sec. 18 and 19, T. 11 N., R. 2 W. The trace of the fault, where it has been defined on the pre-Pennsylvanian surface, is almost a straight line, trending northwest and southeast parallel with the axis of the fold.

The downthrown side of the fault remained almost stationary while the upthrown side was rising. From the projection of the regional dips in the immediately surrounding area it appears that the downthrown side of the fold did not subside more than 400 feet, the major part of this settling probably occurring in Pennsylvanian time. Soon after the area west of the fault began to rise, erosion began. Approximately 1,800 feet of sediments were removed from the crest of the fold, including the "Mississippi lime," Chattanooga shale, Hunton limestone, Sylvan shale, Viola limestone, the Simpson group, and about 225 feet of Arbuckle limestone. The total vertical movement in the structure was about 2,400 feet. The fault scarp, which is now about 600 feet in height (Fig. 7), was probably not more than 150 feet high when the Pennsylvanian seas submerged the peneplaned fold. This relatively small relief at the fault scarp is evidenced by thickening in the Cherokee section, lowest Pennsylvanian, of 100-150 feet on the downthrown side of the fault. That the uplift of the anticline was gradual is shown by the fact that on the downthrown side of the fault, in certain areas which are now 300 feet below the top of the fault scarp, the Pennsylvanian beds rest on the Hunton limestone, indicating that erosion had removed the Mississippian rocks and part of the Hunton group before this area was protected by the rising fault scarp (Fig. 7).

Following this period of folding, faulting, and erosion, Pennsylvanian beds of upper Cherokee age were deposited on the truncated surface (Fig. 8). Considering the magnitude of the folding and the quantity of material removed from the upthrown side of the fold, there was very little relief on the pre-Pennsylvanian erosion surface. The

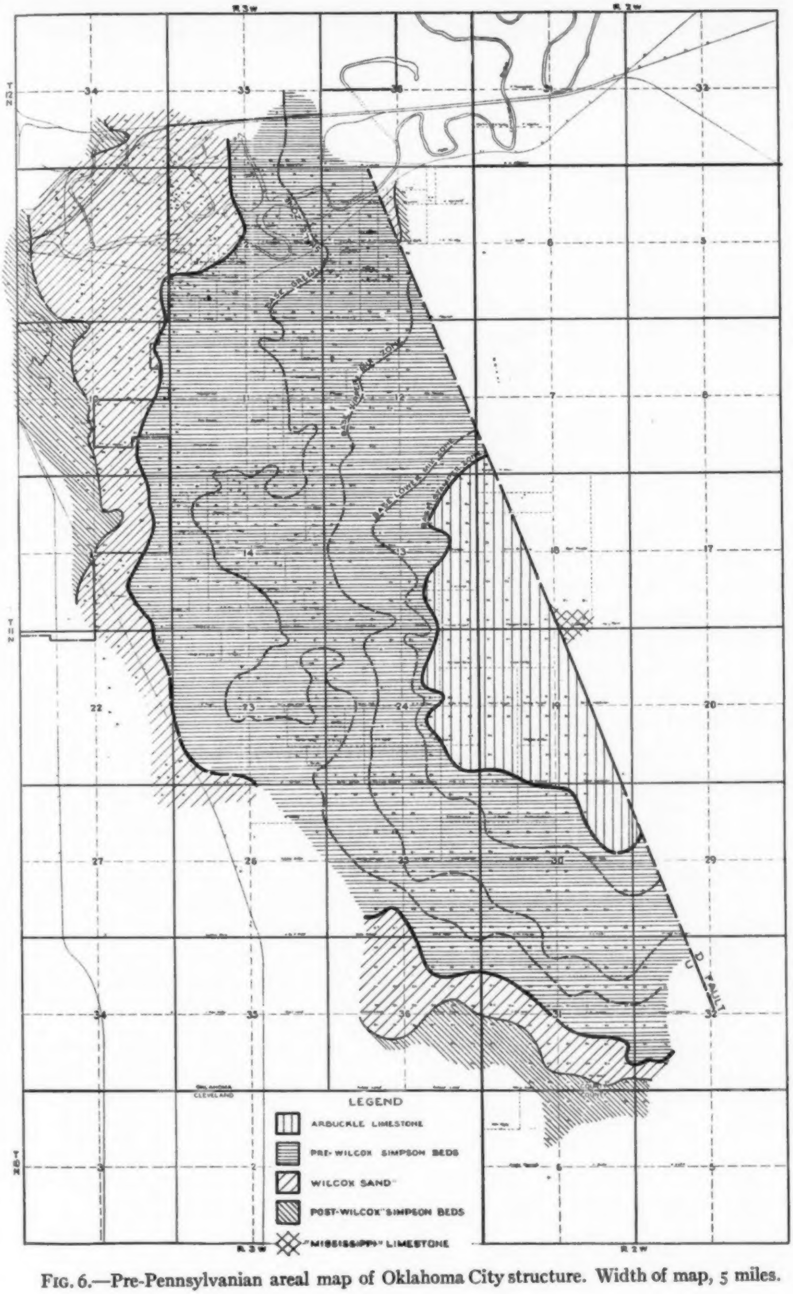

FIG. 6.—Pre-Pennsylvanian areal map of Oklahoma City structure. Width of map, 5 miles.

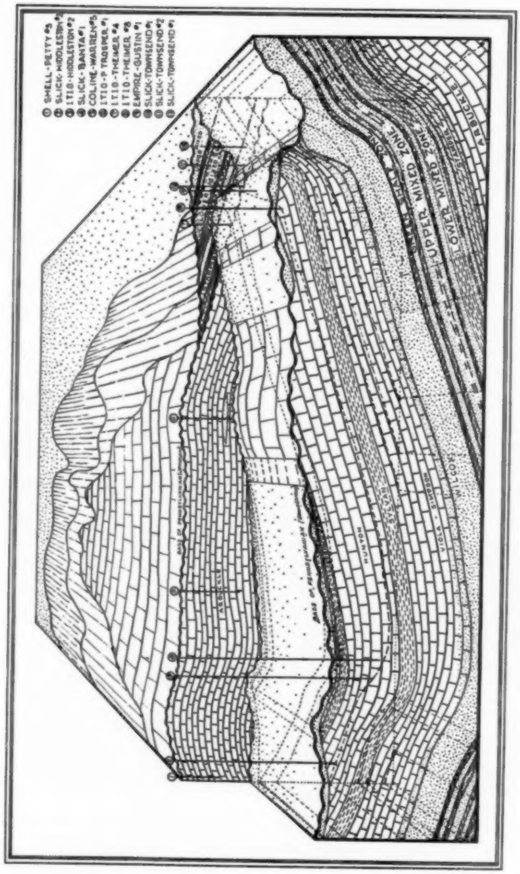

FIG. 7.—Section of fault plane. Pennsylvanian beds have been stripped off on upthrown and downthrown sides of fault, exposing pre-Pennsylvanian beds in fault scarp. Point of maximum throw is at highest structural point on upthrown side. On upthrown side of fault, beds dip sharply down north and south away from crest of fold. On downthrown side, beds dip sharply up north and south away from "low" in Sec. 18, T. 11 N., R. 2 W.

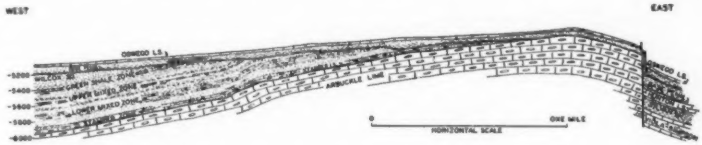

FIG. 8.—Generalized cross section of Oklahoma City field, showing relation of Lower Pennsylvanian to pre-Pennsylvanian beds.

pre-Pennsylvanian hill was completely buried soon after submergence began. The Cherokee shale section shows only a small thinning locally and is present on the entire anticline, including the crest. In one well in the field the "Oswego" limestone lies on the Arbuckle limestone, the "Cherokee" being entirely absent. Other wells in this same area, however, show as much as 50 feet of Cherokee section between the "Oswego" limestone and the pre-Pennsylvanian beds. Approximately 100-150 feet of "Cherokee" beds are normally present over most of the anticline on the upthrown side. A few small, isolated patches of erosional débris were left on the pre-Pennsylvanian peneplaned surface, but on the whole it was swept remarkably clean, the Pennsylvanian beds in the producing part of the field resting directly on pre-Pennsylvanian rocks, ranging from Simpson to Arbuckle limestone in age (Fig. 6). Very little pre-Pennsylvanian débris is present in the basal Pennsylvanian beds. Simpson sand grains and green shale fragments have been noted in the basal 10-20 feet of the Pennsylvanian in several wells. Asphaltites occur in many places at the pre-Pennsylvanian-Pennsylvanian contact. Erosional débris, 20-40 feet in thickness, is present on the downthrown side, where it rests on beds ranging in age from Ordovician to Mississippian.

The cross sections (Figs. 9, 10, 11, and 12) show in vertical section the relation between the pre-Pennsylvanian structure and topography and the overlying Pennsylvanian beds.

Following the submergence of the truncated structure, approximately 6,200 feet of Pennsylvanian and Permian sediments were deposited, apparently in unbroken sequence. However, the area was not wholly undisturbed by diastrophic movements during this period, although the evidence indicates that they were relatively slight as compared with those which occurred at the close of Mississippian time. During middle or late Pennsylvanian (there is no conclusive evidence to indicate the exact time), the structure was tilted slightly south-southwest, with attendant flattening in the north and northwest parts

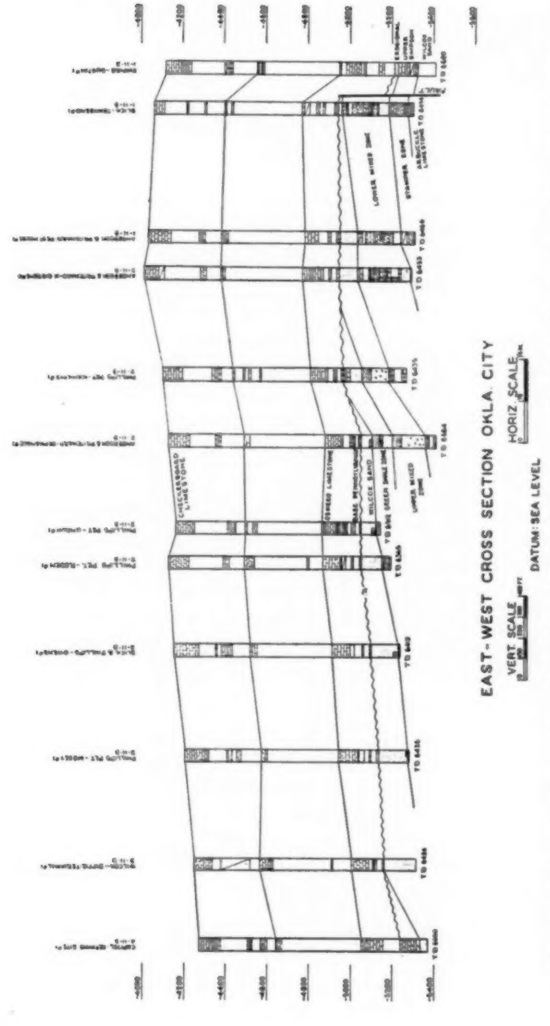

FIG. 9.—East-west cross section through north end of Oklahoma City field, showing Lower Pennsylvanian and pre-Pennsylvanian formations. Along line *AA* (Fig. 16).

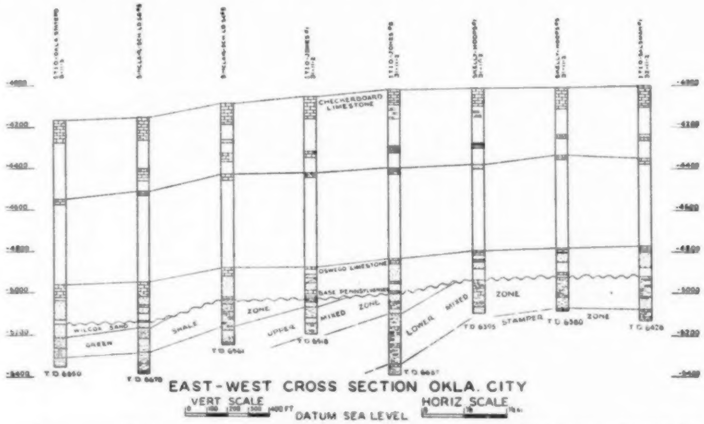

FIG. 10.—East-west cross section through south end of Oklahoma City field, showing Lower Pennsylvanian and pre-Pennsylvanian formations. Along line *BB* (Fig. 16).

of the field, and steepening in the south and southwest parts. In addition to the tilting, this Pennsylvanian disturbance accentuated several transverse west-east folds which had their inception in pre-Pennsylvanian rocks.

During Pennsylvanian time, possibly during the disturbance that tilted the fold, there was additional movement along the pre-Pennsylvanian fault. The upthrown side rose slightly while the downthrown side was subsiding. The amount of the subsidence, which possibly can be attributed to readjustment after overloading by Pennsylvanian sediments, was 200-300 feet. This movement is reflected in the Pennsylvanian beds by steep dips over the pre-Pennsylvanian scarp (Figs. 13, 14, and 15), and by shearing in the Oswego limestone and possibly in several of the competent beds higher stratigraphically. The readjustment of the structure during Pennsylvanian time accounts for the fact that there is a thickening of only 150 feet in the basal Pennsylvanian sediments east of the fault scarp, the height of which is now 600 feet.

Following the Pennsylvanian disturbance there must have been some folding in Permian or post-Permian time, as it is not probable that the formation of the very pronounced surface structure was due to differential settling of the Permian-Pennsylvanian sediments over the pre-Pennsylvanian topography.

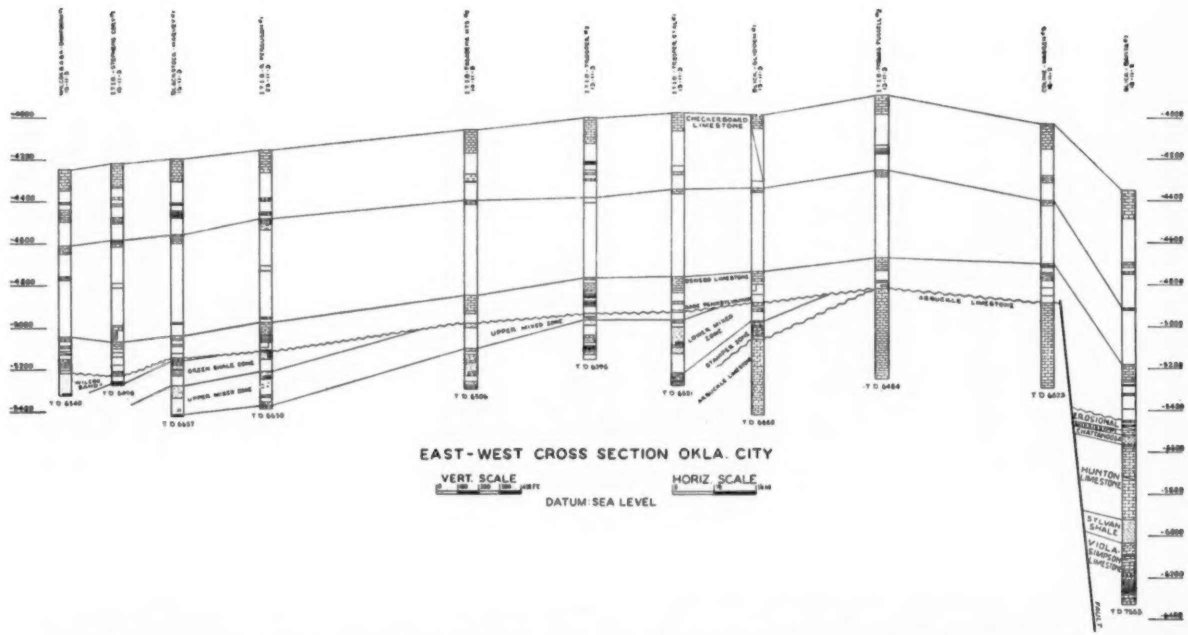

FIG. 11.—East-west cross section through middle of Oklahoma City field, showing Lower Pennsylvanian and pre-Pennsylvanian formations. Along line *CC* (Fig. 16)

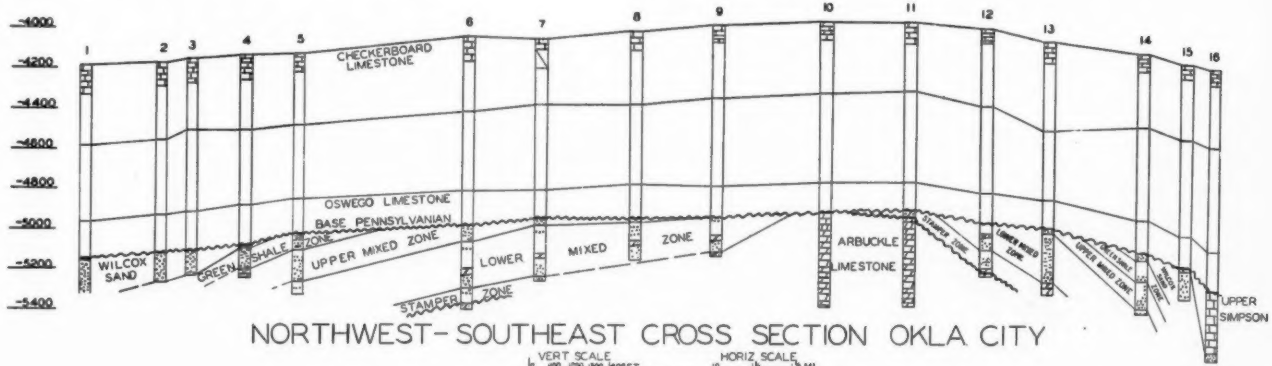

FIG. 12.—Northwest-southeast cross section through Oklahoma City field, showing Lower Pennsylvanian and pre-Pennsylvanian formations. Along line *DD* (Fig. 16). Following is list of wells, with location by section, township, and range; and total depth in feet.

1.	Jamieson-Grimes	Fee No. 1, 34-12-3, T. D. 6,505
2.	Phillips & Anderson-Pritchard	Westfall No. 1, 3-11-3, T. D. 6,434
3.	Phillips Petroleum Co.	Sam No. 1, 3-11-3, T. D. 6,400
4.	Slick-Urschel	Central No. 1, 3-11-3, T. D. 6,410
5.	I. T. I. O. Co.	Coppinger No. 1, 11-11-3, T. D. 6,530
6.	Slick-Urschel	Page No. 2, 14-11-3, T. D. 6,629
7.	I. T. I. O. Co.	H. G. Trosper No. 7, 14-11-3, T. D. 6,493
8.	I. T. I. O. Co.	Trosper No. 2, *et al.*, 13-11-3, T. D. 6,396
9.	Coline Oil Co.	Olds No. 1, 24-11-3, T. D. 6,377
10.	I. T. I. O. Co.	Oklahoma City No. 1, 24-11-3, T. D. 6,624
11.	Sinclair	Stamper No. 1, 30-11-2, T. D. 6,646
12.	I. T. I. O. Co.	Nettie Emerson No. 8, 30-11-2, T. D. 6,530
13.	I. T. I. O. Co.	Lillie Jones No. 3, 31-11-2, T. D. 6,595
14.	Sinclair	Vencl No. 7, 31-11-2, T. D. 6,675
15.	Sinclair	Vencl No. 16, 31-11-2, T. D. 6,602
16.	Prairie Oil & Gas Co.	Sudik No. 1, 5-10-2, T. D. 6,896

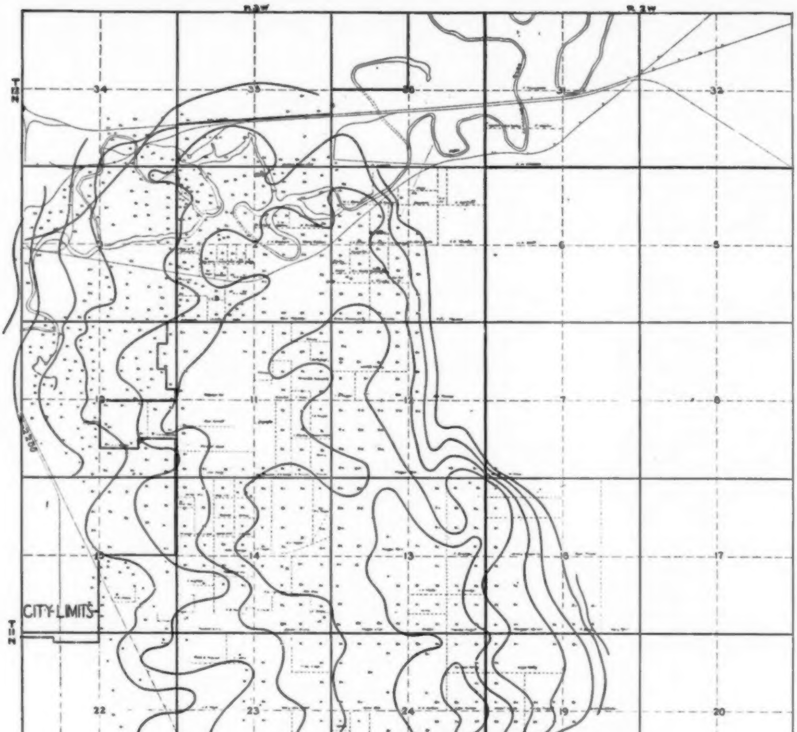

FIG. 13.—"Pawhuska" limestone structure map of Oklahoma City field. Width of map: 5 miles. Contour interval: 50 feet. Datum: sea-level.

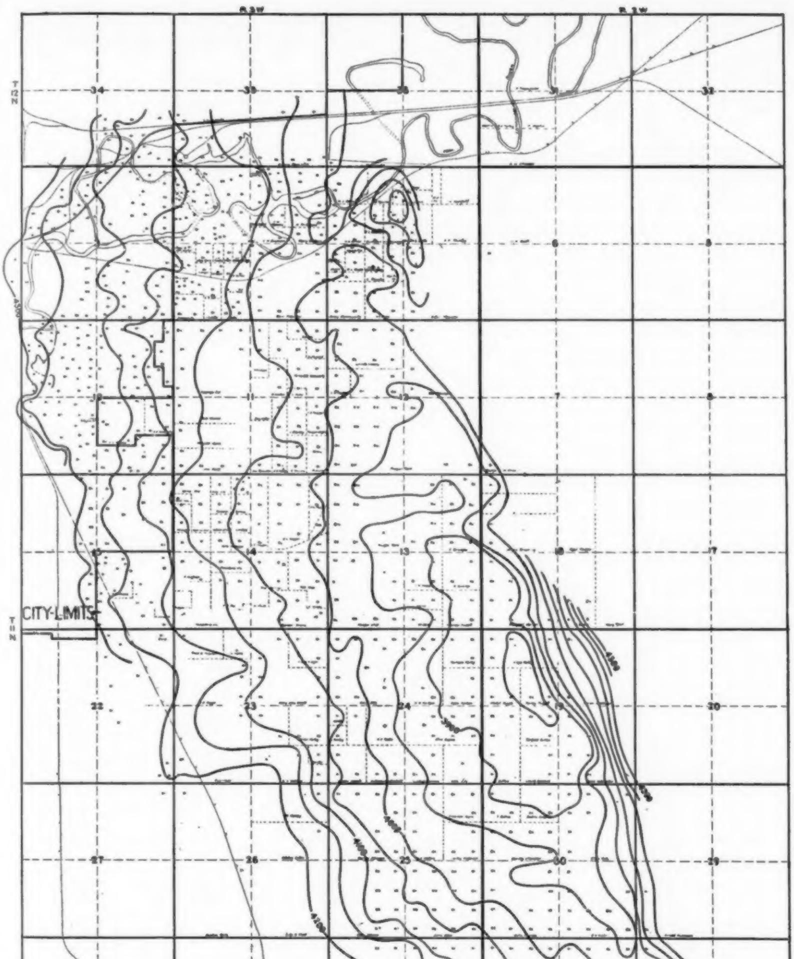

FIG. 14.—"Checkerboard" limestone structure map of Oklahoma City field. Width of map: 5 miles. Contour interval: 50 feet. Datum: sea-level.

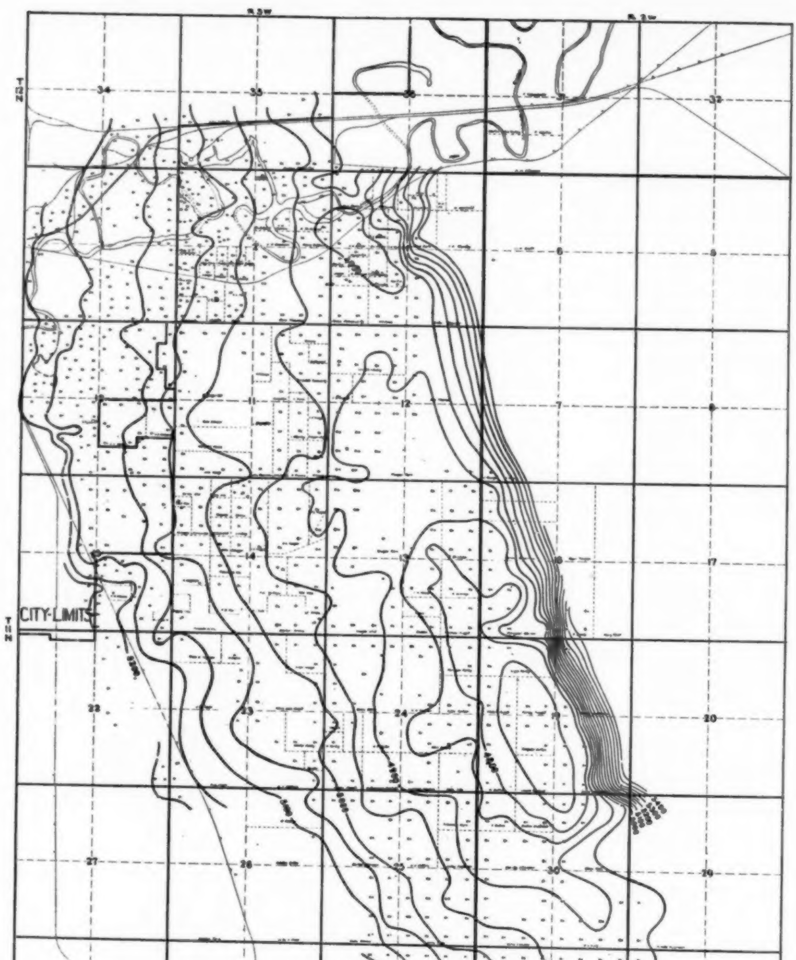

FIG. 15.—Base of Pennsylvanian structure map of Oklahoma City field. Width of map: 5 miles. Contour interval: 50 feet. Datum: sea-level.

The Oklahoma City anticline, as mapped on the Garber sandstone (Fig. 4), is very similar, excepting in degree of dip, to that mapped on the "Pawhuska" limestone (Fig. 13), the "Checkerboard" limestone (Fig. 14), and the base of the Pennsylvanian (Fig. 15). All features shown on the Permian beds are accentuated with depth. The steep dip in the east limb which is indicated on the surface map becomes very pronounced in the lower beds. The Pennsylvanian beds begin to break sharply east over the pre-Pennsylvanian fault scarp. The axis shifts east with depth. As shown on the structure maps, the "high" shifts with depth from the east half of Sec. 24, T. 11 N., R. 3 W., to a point just west of the center of Sec. 19, T. 11 N., R. 2 W. A noticeable shortening of the intervals from the "Pawhuska" down occurs over the crest of the fold. This shortening is undoubtedly related to the eastward shift of the "high."

The structure in the pre-Pennsylvanian rocks is mapped on the base of the "Wilcox sand" (Fig. 16). The dips in the pre-Pennsylvanian beds are much steeper than those in the overlying Pennsylvanian, being as high as 11°, locally. The "high" on the pre-Pennsylvanian structure is in the center of Sec. 19, T. 11 N., R. 3 W.

DEVELOPMENT—OIL AND GAS HORIZONS

Arbuckle limestone.—The first oil produced from the Arbuckle limestone in the Oklahoma City field was encountered in the Indian Territory Illuminating Oil Company's Oklahoma City No. 1, the discovery well of the field. As previously noted, the initial production of this well was 2,895 barrels of oil in 14 hours, natural flow. The Arbuckle limestone was subsequently tested by 114 wells in an area of 1,660 acres. Of this number, three wells produced no oil from the limestone and four others had a total production of less than 1,000 barrels each from this source. Deducting 70 acres from the total area for these wells leaves a productive area of 1,590 acres (Fig. 22) with 107 producing wells, or an average of 14.8 acres per well. The entire area has been thoroughly tested although on some of the larger leases not all the inside locations have been drilled.

The total initial production figured on a 24-hour basis was 1,184,533 barrels for 107 wells, or an average of 11,070 barrels per well. The average initial 24-hour gas volume figured in the same manner was 21,239,000 cubic feet per well. The largest initial production was encountered in the Indian Territory Illuminating Oil Company's Thomas-Fuzzell No. 1, SW. 1/4, SE. 1/4, SE. 1/4, Sec. 13, T. 11 N., R. 3 W., which came in for a

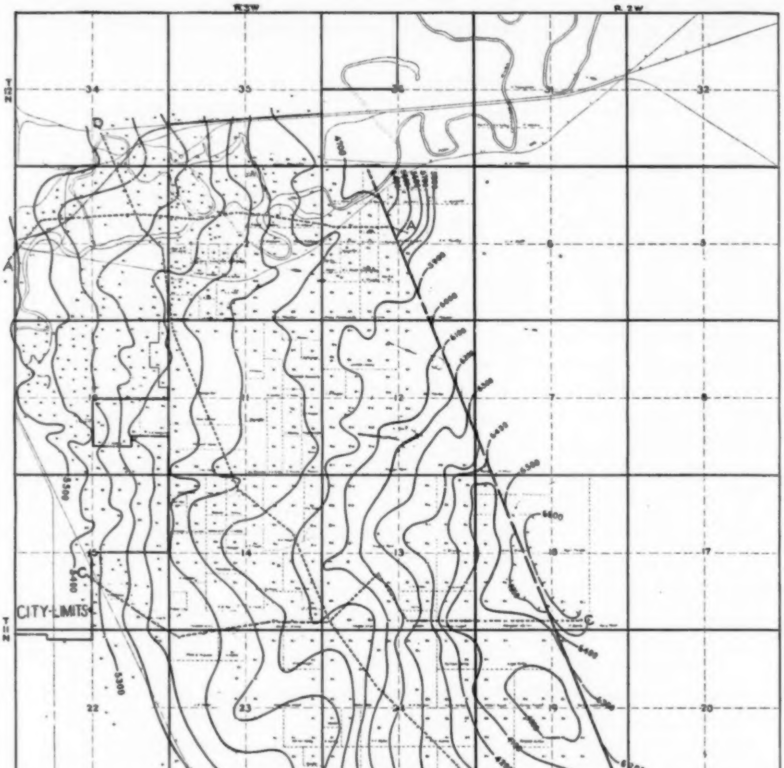

FIG. 16.—Base of "Wilcox" sand structure map of Oklahoma City field. Width of map: 5 miles. Contour interval: 50 feet. Datum: sea-level.

gauged initial of 43,557 barrels in 24 hours and 35 minutes. The largest accumulated production to date has been made by the Indian Territory Illuminating Oil Company and Cromwell-Franklin's Mabel Fuzzell No. 1, SW. 1/4, SW. 1/4, NW. 1/4, Sec. 19, T. 11 N., R. 2 W., with a total to February 1, 1932, of 1,223,868 barrels.

The 24-hour potential of the Arbuckle limestone area on February 1, 1932, was approximately 5,685 barrels from 34 wells, or an average of 167 barrels per well.

The average penetration of wells in the limestone area is 395 feet, with a maximum of 876 feet in the Indian Territory Illuminating Oil Company's Emerson-Joyce No. 1, NW. 1/4, NE. 1/4, NE. 1/4, Sec. 25, T. 11 N., R. 3 W. Numerous tests, both while drilling and while plugging back, indicate that a penetration of as much as 225-250 feet is necessary to obtain an appreciable amount of oil from the limestone. No constant relation of penetration to production has been observed, although most of the larger wells penetrated 450-500 feet of the limestone. Considerable evidence of porosity in the nature of small cavities lined with well developed dolomite crystals is found in samples from the lower part of the Arbuckle limestone penetrated in wells. Additional evidence of cavities as large as 7 feet in diameter was indicated by drilling action and by the loss of circulation while drilling in this zone. The production is largely confined to the porous parts of this lower zone.

The Arbuckle oil has a gravity varying from 37.5° to 39.5° Bé. at 60° F. As shown by the representative analysis, the character of this oil is very similar to that of the oil from the Simpson beds. The maximum initial temperature recorded on oil from Arbuckle limestone wells in this field was 102° F. in the Indian Territory Illuminating Oil Company's George Button No. 5, Sec. 19, T. 11 N., R. 2 W., which made some salt water on the initial test. A minimum temperature of 48° F. was reported in the Indian Territory Illuminating Oil Company's Sarah Hiddleston No. 1, Sec. 19, T. 11 N., R. 2 W. This well had an abnormally high gas volume on the initial test which probably accounts for the low temperatures. The average initial temperature for limestone wells is approximately 70.5 degrees F.

A maximum initial shut-in pressure of 2,300 pounds per square inch was shown by several of the early wells drilled in the limestone area. The actual formation pressure was no doubt slightly in excess of this figure, as the well-head pressure is affected by the amount of fluid in the hole. The average initial well-head pressure for many wells was 1,820 pounds per square inch. Some of the present producing limestone

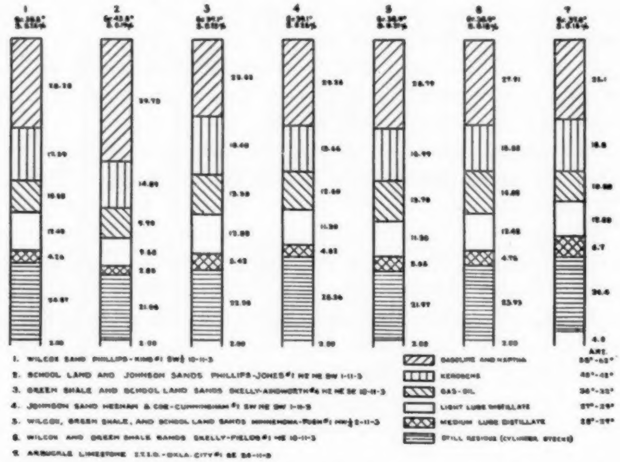

FIG. 17.—Comparative analyses of crudes from various producing horizons in Oklahoma City field.

wells show a well-head pressure varying from 1,800 to 2,000 pounds, when closed in and the pressure allowed to build up.

The initial development of the limestone area was begun on a basis of one well to 40 acres. Six wells were drilled with this spacing. Later wells were drilled with a spacing of one well to 10 acres largely on account of division of leases and over-enthusiasm regarding the productivity of the limestone, judged from large initial production. However, on large leases some of the inside locations were not drilled. Experience has proved conclusively that a spacing of one well to 40 acres would have been ample development.

Production records as of February 1, 1932, show a total production from the Arbuckle limestone of 16,576,295 barrels for 107 producers in an area of 1,590 acres. These figures give an average of 154,918 barrels per well and a recovery of 10,430 barrels per acre.

Lower Simpson.—The total area of the pre-Pennsylvanian outcrop of the lower Simpson is 6,484 acres. Deducting 528 acres for the area in which wells penetrated a thin section of relatively unproductive Simpson beds and produced oil in the Arbuckle limestone, leaves an estimated productive area of 5,956 acres. This area is 46.6 per cent of the total productive area of the field. Of the 5,956 acres, 4,943 acres or 83.6 per cent are considered as developed.

A total of 440 wells were drilled in this developed area, giving an average acreage per well of 11.2 acres. The usual spacing has been one well to 10 acres, some of the inside locations being omitted on the larger leases.

The discovery well in the lower Simpson sands was the Coline Oil Corporation's Olds No. 1, center of SE. ¼, NW. ¼, Sec. 24, T. 11 N., R. 3 W., which was completed on June 27, 1929, with an initial production of 4,173 barrels of oil in 24 hours, natural flow.

The total initial production of the 440 wells, calculated on a 24-hour basis, was 3,026,447 barrels, or an average of 6,878 barrels per day. The largest initial production in this zone was made by the Skelly Oil Company's Hoopes No. 1, Sec. 31, T. 11 N., R. 2 W., which flowed at the rate of 29,600 barrels per day. Initial productive rates ranged from this figure down almost to zero for wells with excessive gas volumes.

On February 1, 1932, the calculated 24-hour potential of the lower Simpson zone was 1,903,051 barrels from 421 oil wells, an average of 4,520 barrels per well.

The lower Simpson beds penetrated range in thickness from approximately 100 feet in wells near the crest of the anticline to 440 feet for wells on the flanks, which enter the Simpson higher stratigraphically (Fig. 8). The production of the lower Simpson wells, particularly those completed in the upper sands, is governed largely by the porosity of the sand. Where the sands are high structurally, they contain large volumes of gas.

The average porosity of the Kinter sandstone (Fig. 5) ranges from 18 to 20 per cent. The porosity of the upper sands in the lower Simpson zone is variable from place to place, but the average is approximately 15 per cent. The sands in this zone appear to be well saturated except where the porosity is greatly reduced by cementation.

The oil from the lower Simpson zone has a gravity varying from 37.5° to 39° Bé. and an initial temperature varying from 60° to 80° F. Maximum temperatures as high as 104° F. were recorded on a few wells, which showed some water on the initial gauge. Fluid from wells with excessive gas volumes had temperatures ranging down to 27° F. An average analysis of lower Simpson oil is shown in Figure 17.

Maximum initial well-head pressures of 2,400 pounds per square inch were recorded on lower Simpson sand wells. This pressure was recorded on a gas well with very little fluid in the hole and no doubt approaches very closely the initial formation pressure. The average initial shut-in pressure for a large group of wells was 1,700 pounds per square inch.

On February 1, 1932, production records showed an accumulated production of 34,428,554 barrels for the lower Simpson zone. This is a recovery of 78,247 barrels per well, and 6,965 barrels per acre of developed area.

"*Wilcox sand.*"—The "Wilcox," being the youngest of the producing sandstones in the Simpson group, is the farthest removed from the crest of the fold. Due to the relatively low dips on the base of the Pennsylvanian beds, the "Wilcox sand" is encountered at approximately the same depths, 6,200-6,500 feet, as the stratigraphically lower producing zones closer to the top of the anticline. The productive zone in the "Wilcox sand" varies in width from 1.5 miles where the dips are relatively low to as little as .25 mile where the dips are steep.

The total productive area of the "Wilcox sand" is estimated to be 5,233 acres, or 40.8 per cent of the total estimated productive area of the field. On February 1, 1932, 2,120 acres, or 40.3 per cent of the total area of the zone, had been developed. Of the total estimated productive acreage, 3,433 acres are within the corporate limits of Oklahoma City. Of the area within the city limits, 1,695 acres, or 49.4 per cent, are in the U-7 zone, that part of the city open to drilling. The remaining 1,738 acres of the area within the city limits underlie a closely built residential section of the city in which drilling is prohibited. Some of the oil in this restricted area will undoubtedly be produced from wells drilled in the unrestricted areas adjoining it. At present, it is estimated that there are 1,375 acres in the productive "Wilcox sand" zone which can and will be drilled.

The first well to produce from the "Wilcox sand" was the Indian Territory Illuminating Oil Company's Mary Sudik No. 1, NE. ¼, NE. ¼, SW. ¼, Sec. 31, T. 11 N., R. 2 W. This well blew out while being drilled at a depth of 6,472 feet. After blowing gas for approximately 2.5 days, the well began showing oil, the amount of which increased to an estimated 40,000-60,000 barrels per day. After two unsuccessful attempts the well was closed in on the eleventh day with a special packed die nipple. At the time the well was blowing wild it was not realized that it was producing from the "Wilcox sand" as the east offset had not encountered it. The first well in which the "Wilcox sand" was definitely recognized was the Sinclair Oil and Gas Company's School Land 67 No. 1, Sec. 36, T. 11 N., R. 3 W.

The first well to produce from the "Wilcox" in the north end of the field was the Hall-Briscoe Holmes No. 1, located on a 60-acre lease, in the SE. ¼ of Sec. 10, T. 11 N., R. 3 W., just outside the city limits.

The Holmes No. 1 penetrated the sand near the east edge of its pre-Pennsylvanian outcrop, and only the basal part, the lower 20 feet of which is largely interbedded with light green shale, was drilled. It was completed on May 27, 1930, and flowed 8,511 barrels of oil in 12 hours with 14,500,000 cubic feet of gas. The completion of the Holmes No. 1 accelerated leasing within the corporate limits of Oklahoma City, and inaugurated an intensive town-block drilling campaign.

There have been 331 wells which have drilled into or through the "Wilcox sand." Thirteen of these wells were low structurally. Ten of these 13 wells were dry and abandoned with water in the sand; 2 were plugged back to the upper Simpson; and one was plugged back to an unconformity sand at the base of the Pennsylvanian. Six more wells, located near the edge of the anticline, showed water either on their initial production test or soon thereafter. One of these wells was plugged back to the Pennsylvanian, 3 to higher levels in the "Wilcox," and 2 have not yet been plugged back. Thus, of the 331 wells completed only 3.9 per cent have been dry and abandoned or plugged back to horizons above the "Wilcox." Two wells are classified as gas wells. They make some high-gravity gasoline with the gas. In two wells that were drilled through the "Wilcox sand" into Simpson sands below, the "Wilcox" was cased off and these wells are producing from the Lower Simpson. One well that had been completed and bailed had not been tested for production up to February 1, 1932. A total of 312 wells are now producing oil from the "Wilcox sand." Out of the total of 331 wells, 82 wells or 24.6 per cent, after being drilled through the "Wilcox," have penetrated one or more of the producing horizons in the Simpson below. The production of oil and gas from 80 of these wells is shown in this report as from the "Wilcox sand," although a small part of it is from the Lower Simpson.

The 318 wells which have produced from the "Wilcox sand" have a total initial production, calculated on a 24-hour basis, of 9,638,507 barrels, or an average of 30,309 barrels per well. This calculation is based for most wells on initial production tests varying from 4 to 8 hours. Several exceptionally large wells have been completed in the "Wilcox sand." The largest well yet completed is the Westgate Oil Company's Carey No. 3, Sec. 34, T. 12 N., R. 3 W., which produced at the rate of 86,424 barrels per day on an initial 8-hour test. The last potential gauge on this well was 96,541 barrels per day. The Phillips Petroleum Company's McBeth No. 1, NE. 1/4, Sec. 10, T. 11 N., R. 3 W., on May 28, 1931, produced 9,469 barrels of oil in 2.25 hours, or at

the rate of 101,002 barrels daily. The gas volume was gauged at 67,000,000 cubic feet per day. There are several wells with initial production rates in excess of 50,000 barrels per day.

The 305 "Wilcox sand" wells on which records of initial gas volumes are available showed a total of 12,048,704,600 cubic feet per day, or an average per well of 39,503,949 cubic feet. The maximum initial gas volume from a "Wilcox" well was 202,000,000 cubic feet on the Slick-Urschel's Trumbley No. 1, Sec. 2, T. 11 N., R. 3 W.

The 331 wells which encountered "Wilcox sand" penetrated a total of 34,431 feet of sand or an average of 104 feet per well. The maximum penetration on record is 262 feet, drilled in the Phillips Petroleum Company's Clayton No. 1; however, in this well the section was abnormal because the upper part was tightly cemented with secondary quartz and dolomite.

The maximum normal section of sand is found in the Sinclair Oil and Gas Company's School Land 67 No. 7, Sec. 36, T. 11 N., R. 3 W., where 226 feet of sand was penetrated. The "Wilcox" is normally 220 feet thick where a complete section of the sand is present.

Wells that after penetrating the "Wilcox sand," were drilled to lower Simpson producing horizons are mostly drilled in the thin inner fringe of the producing zone. The "Wilcox" in these wells averages only 65.7 feet per well for 82 wells, as compared with 116 feet per well in those wells which drilled only the "Wilcox sand."

The initial production of a well in this sand is controlled by the thickness of sand drilled, all other factors being the same, up to a certain sand thickness. Beyond this point, the drilling of additional sand does not materially increase the production of the well. The limiting thickness of sand varies with the size of the casing through which the well is flowing.

The development of the "Wilcox sand" to date has been confined to an area of approximately 1,440 acres in the north part of the field and 680 acres in the south part. The two parts are now separated by an undrilled area. Due to the structural position and lower dips, there is a greater volume of productive sand above the water level in the north area. There seems to be little difference in the physical characteristics of the sand in the two areas. However, due to the more favorable structural conditions, and possibly higher sand porosity, the north area yields larger wells initially and should prove to be the more prolific area.

Up to February 1, 1932, the total recovery of oil from the 312 wells producing from the "Wilcox sand" was 40,390,467 barrels, an average

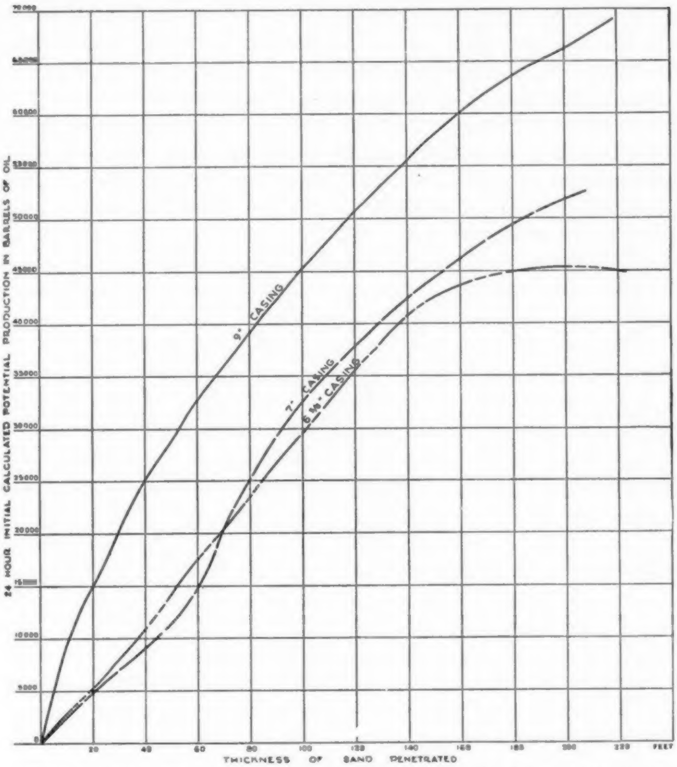

FIG. 18.—Curves showing effect of "Wilcox sand" penetration on initial production, Oklahoma City field.

of 129,453 barrels per well. For the 2,120 developed acres the average production per acre was 19,052 barrels. The average recovery per acre foot to February 1, 1932, was 183.2 barrels.

The decline on the 312 producing "Wilcox" wells, calculated from their initial gauges to their potential production rating as of February 1, 1932, was 11.8 per cent.

The average acreage per well in the developed area of the "Wilcox sand" on February 1, 1932, was 6.4 acres. The usual spacing in the south end of the field is one well to 10 acres, and in the north end, the wells average 5.7 acres. In the W. 1/2, NW. 1/4, Sec. 2, T. 11 N., R. 3 W., there are 31 producing wells, or an average of 2.6 acres per well.

As bottom-hole pressure readings in the "Wilcox sand" are not available, the true reservoir pressure has not been determined. There are a number of well-head pressures available. A comparison of the average maximum shut-in pressures is the nearest approach to bottom-hole, or true reservoir, pressures. In not all of the earlier wells were the shut-in pressures taken. In many wells where readings were taken, no notation was made as to the relation of the reading to the last flow period of the well. Many wells which show 2,000-2,150 pounds pressure a short time after being shut in show as low as 600 pounds before the next opening, dependent on the adjustment of the fluid column in the well. The maximum initial shut-in pressure varies from 2,400 pounds in the south end to 2,350 pounds in the north area.

Temperature readings were taken in several wells either at or shortly after completion and testing. The initial temperatures vary from 34° to 92° F. with an average varying from 63.2° to 70.4° F. The lower temperatures were in wells that had large volumes of gas initially and are due to the cooling action of the expanding gas. The higher temperatures are not excessive and do not necessarily indicate that water is near. Many are in wells with relatively small gas volumes.

The gravity of the oil produced ranges from 37.8° to 40.4° Bé. on initial tests from several wells that drilled only the "Wilcox sand." The average gravity for this group of wells is 39° Bé. The gravity in several wells has been raised as much as 2° Bé. through the application of back pressure. There seems to be a higher gravity on the wells located structurally high as compared with wells structurally lower. An average analysis of "Wilcox sand" oil is shown in Figure 17.

Porosity tests taken on samples from each foot of a 9-foot core recovered from 6,450-6,464 feet in the Mary Sudik well No. 1, Sec. 31, T. 11 N., R. 2 W., show 20-25 per cent with an average of 22.6 per cent porosity. A large part of the "Wilcox sand" is so loosely cemented that it is nearly impossible to obtain satisfactory recoveries in coring. These loosely bonded portions will probably have a greater porosity than that shown in cores recovered. In the rotary cuttings, the sand is present as loose grains, showing no evidence of having been cemented. Some of this loose sand flowed from a well was packed as tightly as possible while shaking. This packed sand showed a 30 per cent porosity. The saturation has not been accurately determined; however, the larger portion of the sand is very thoroughly saturated with oil. Although it is impossible at present to give an estimate of the ultimate recovery from the "Wilcox," it appears, in considering the average thickness,

the porosity of the sand, and the recovery to date, that it will be very large.

On February 1, 1932, the calculated 24-hour potential for the 312 wells in the "Wilcox" zone was 8,499,321 barrels, or an average of 27,241 barrels per well.

Pennsylvanian oil and gas horizons.—On February 1, 1932, there were 40 wells producing oil or gas from 6 distinct Pennsylvanian horizons. The production, which is largely gas, is encountered in beds ranging from an average depth of 4,020 feet to 6,120 feet. The initial gas production ranges in volume from 158,000,000 cubic feet maximum to 2,000,000 cubic feet minimum (Table I).

TABLE I

Horizon	*Number of Wells*	*Approx. Depth in Feet*	*Max. Gas Production Million Cubic Feet*	*Min. Gas Production Million Cubic Feet*	*Initial Oil Production Barrels*	*Average Gas Production Million Cu. Ft.*	*Remarks*
Hoover	2	4,020	158	47½	....	102¾	
Layton	5	4,930	80	44	....	51 3/5	
Oölitics	4	5,460	18	14	216	15 1/3	Only 1 well making oil from oölitics
Oswego	7	5,990	67	5	....	23 4/7	
Osw.-Prue	7	5,990	55	7	....	47	
Prue	13	6,090	80	2	203	40	Only 1 well making oil from Prue
Unconform.	2	6,200-6,800	3	100	....	1½	Only 2 wells testing this sand

There has been no attempt made to develop this production, because there is only a limited market for the gas. As the six Pennsylvanian horizons that have been tested and found productive are only partly developed, there is little information available and the discussion is necessarily generalized. Most of the tests of Pennsylvanian sands have been made in the course of drilling wells now producing from pre-Pennsylvanian horizons. A total of 65 wells have tested the Pennsylvanian formations. Pennsylvanian horizons are producing in 3 wells that were dry in the pre-Pennsylvanian sands and were plugged back. Thirty-six wells are producing from Pennsylvanian beds in which the pre-Pennsylvanian production, largely from the Arbuckle limestone, has been exhausted. There are 6 wells in which all the Pennsylvanian horizons

have been tested and found dry, after which the wells were plugged to the surface. Also there are 10 wells in which the Pennsylvanian has been dry in at least one horizon tested.

TABLE II

WELLS IN WHICH PENNSYLVANIAN HAS BEEN FOUND DRY

Company	*Farm Name*	*Location Sec. T. R.*	*Horizon Tested*	*Results*
Coline	Warren No. 5	SE. SE. SW. 18-11-2	Oölitic	Salt water
C-Franklin	Reynolds No. 1	NE. NE. SW. 6-10-2	Endicott	Salt water
I. T. I. O.	Emerson-Joyce No. 1	NE. NE. 25-11-3	Tonkawa	Salt water
I. T. I. O.	Foster No. 1	NE. NE. SW. 24-11-3	Layton	Salt water, showing oil and gas
I. T. I. O.	Reynolds No. 2	SE. NE. NW. 6-10-2	All horizons	
I. T. I. O.	Sudik No. 11	NW. SW. SW. 31-11-2	All horizons	
I. T. I. O.	Trosper No. 1	C. NE. SW. 13-11-3	Sand above Pawhuska and Layton	Salt water
I. T. I. O.	Trosper-Hughes No. 1	SE. NE. SE. 11-11-3	Sand above Pawhuska	Salt water
I. T. I. O.	Watters No. 3	SW. SW. NE. 25-11-3	Tonkawa	Salt water showing oil and gas
Mid-Kansas	Fortson No. 1	C. SE. NE. 24-11-3	Layton	Salt water
Mid-Kansas	Fortson No. 2	C. NW. NE. 24-11-3	Layton	Salt water
Prairie	Sudik No. 1	NW. NW. 5-10-2	All horizons	Salt water
Sinclair	Sch. Ld. 67 No. 4	NE. SE. SE. 36-11-3	All horizons	Salt water H.F.W.
Sinclair	Sch. Ld. 67 No. 6	SW. SE. SE. 36-11-3	All horizons	Salt water H.F.W.
Slick	Hiddleston No. 2	19-11-2	Pawhuska and Hoover	Salt water H.F.W.
Slick	Townsend No. 2	1-11-3	Probably no test in Layton	Dry

The Pennsylvanian horizons generally have been tested in two ways: (1) by drilling or coring into the sand and testing with patented drill-stem testers, or (2) by plugging back with chat and cement from pre-Pennsylvanian horizons and ripping or shooting off the casing. In several wells the upper horizons have been tested by cementing casing just above the top of the sand to be tested and then drilling the well in. In addition to the production tests made on Pennsylvanian horizons, further evidence of the presence of gas in several of these horizons has been given by blow-outs during drilling operations.

Accurate records of shut-in pressures on Pennsylvanian formations are difficult to obtain. The available data show pressures of 1,500-1,600 pounds per square inch in the "Hoover" sandstone, 1,475 pounds per square inch in the Endicott sandstone, and 1,725 pounds per square inch in the "Layton" sandstone.

DRILLING METHODS

As the Oklahoma City field is one of the first fields in the Mid-Continent to produce from an average depth of more than 6,200 feet, a brief account of the drilling and production problems and their relation to the geology of the field is pertinent.

Cable tools.—Cable-tool drilling of wildcats in the area had demonstrated that it was impracticable to drill with this method. Consequently, the discovery well in the field was drilled with rotary equipment to a depth of 6,402 feet, 237 feet into the Arbuckle limestone, and completed, after running the flow string of casing, by drilling out the plugs with cable tools. Cable tools were used on several early wells for "drilling in" but, with few exceptions, were unsatisfactory.

Equipment.—General practice is to completely wall the cellar and runways with concrete. Steel derricks are used exclusively. The standard derricks in use are 122 feet high on a 24- ×24-foot base. Working mud pits have about 5,000-barrel capacity and are divided into 6 or 8 compartments to accomplish settling of the larger particles in suspension in the drilling mud. A reserve pit of approximately 10,000-barrel capacity is provided.

Steam power is used almost exclusively. A few wells have been drilled satisfactorily with electric power. The general practice is to use three or four 125-horse power, 300-350-pound working pressure boilers. Prime movers are 12 × 12 twin roller-bearing engines. Pumps of various sizes are used, but best results are obtained with the larger pumps. Standard rotary tables, draw works, crown and traveling blocks of the heaviest design are used. One Doheny-Stone Hydrill rotary has been in operation in the field, but has not made exceptional drilling time. Weight indicators are part of the regular drilling equipment and are probably largely the cause for the remarkably small percentage of crooked holes drilled.

On April 28, 1930, the Corporation Commission of Oklahoma issued an order requiring a string of surface pipe at least 250 feet long cemented from top to bottom; a second string of casing not less than 2,000 feet long cemented to the surface pipe, or with not less than 1,500 sacks;

and a third string of casing to be set on top of the producing horizon and cemented with sufficient cement to reach the bottom of the second string, or not less than 1,500 sacks. The order was issued at the request of the operators in the field in order to make uniform the casing program already commonly used.

The majority of wells in the Oklahoma City field have set 9⅝-inch casing either in the "Checkerboard" limestone or in the "First Oölitic" limestone, from 5,200 to 5,700 feet in depth. The flow string, either 6⅝-inch or 7-inch O. D. pipe, is set at or very near the top of the producing horizon ranging from 6,000 to 6,550 feet in depth. Several wells have been completed with 9⅝-inch O. D. casing set on top of the producing horizon. The first of these wells ran only the surface pipe and the 9⅝-inch casing. Since the order requiring a second string of casing went into effect, wells setting 9⅝-inch casing on top of the sand have set 2,000-2,200 feet of 13⅜-inch pipe. Recently, one operator has run 9⅝-inch pipe to 4,000 feet and set 6⅝-inch casing on top of the sand.

Rotary drill pipe used in the field is standard A. P. I. 6-inch until the 9⅝-inch casing is set. Drilling inside the 9⅝-inch is done with 4-inch A. P. I. and inside the 7-inch or 6⅝-inch with 3-inch A. P. I. drill pipe. Because of the drilling within or in close proximity to the city, practically all the wells are drilled with a float valve in the drill pipe and a blow-out preventer at the well head.

In the 11½-inch hole a few drag, disc, or fish-tail bits are used. The greater part of the hole, however, is drilled with hard formation bits such as the Hughes, Reed, or Chicago Pneumatic.

Water supply system.—An Oklahoma City field drilling well uses approximately 4,000 barrels of water per day for the first 10 days, or the first 3,000 feet of hole. From 3,000 to 5,000 feet the consumption is approximately 2,200 barrels per day, and from 5,000 to 6,500 feet, 1,800 barrels per day. In addition to drilling requirements water is used for oil-pumping boilers, cleaning tanks, fire connections, and camp purposes. To supply their water requirements each of the major operators in the field has built a water supply system. Water is obtained from North Canadian River, from large diameter shallow wells in the river bottoms, water wells drilled in the Garber and Upper Wellington sands, and from ponds near the field. Some water was purchased from the Oklahoma City water system. The peak consumption by the Indian Territory Illuminating Oil Company, major operators in the field during the height of the drilling campaign, was 200,000 barrels per day. Good water wells in the Garber sandstone supply as much as 8,000 barrels per day.

The dug wells in the river bottom have maximum capacities of 15,000 barrels per day.

Oklahoma City drilling regulations.—Drilling for oil or gas is permitted only in that part of the city designated as the U-7 zone, and subject to city ordinance rules. Before starting operations a drilling permit must be obtained at a cost of $1,000.00. A suitable $200,000.00 bond must be provided, which can be reduced to $50,000.00 after the first year if all drilling is completed. All equipment used must conform to specifications of the ordinance. Exhausts must be suitably muffled. A licensed stationary engineer must be in charge of each steam boiler installation whenever pressure is maintained in any of the boilers. All steam fittings must be installed by a steam fitter, licensed by the city. City inspectors have the power to shut down any producing or drilling well when conditions warrant such action.

Cost of completed well.—The early wells in the Oklahoma City field cost approximately $155,000.00 each. Drilling contract price was $12.50 per foot. This contract price is now $7.00 per foot for 6⅝-inch or 7-inch pipe set on top of the sand, and $8.00 per foot for 9⅝-inch casing set on top of the sand. The present cost of a completed 7-inch well is approximately $110,000.00. A 9⅝-inch well completed costs approximately $10,000.00 more. High pressures, large volumes, and the sand produced with the oil necessitate expensive surface hook-ups. These are higher than in most fields, being approximately $25,000.00. Drilling on residential property inside the city limits entails an extra cost of $1,000.00 for a drilling permit and $2,000.00 for a bond. The cost of cleaning the location, moving houses, et cetera, ranges from $2,000.00 to $3,000.00.

Drilling fluid.—The Permian red and brown shales encountered below 500 feet make a good natural drilling mud. The gray shales of the Upper Pennsylvanian are also good mud-making formations. This part of the hole contains many sandstones and limestones which retard drilling considerably, but these shales do not cave badly in ordinary drilling operations. The gray shales between the "Checkerboard" and the "Oölitic" limestones cave badly. This is one of the principal reasons for running the 9⅝-inch casing to the top of the "Oölitic" limestones. Between the "Oölitic" and the "Oswego" the shale drills easily but does not make much mud. If drilled rapidly it does not give any trouble by caving, and is usually drilled with very light mud. The shale between the "Oswego" and the base of the Pennsylvanian generally caves badly, and at this point a fairly thick drilling mud is used. The weight and

character of mud used is usually left to the discretion of the contractor up to the time of drilling the producing formations. After several wells in the field had blown out in the course of drilling, most of the operators exercised stringent control for a time over the weight of drilling mud used. Men were detailed to weigh and record every few hours the weight of drilling fluid, and certain weight fluids were specified by the operators for different drilling depths. However, as the drilling contractors became more experienced in the field and the danger points for blow-outs became better known, this precaution was no longer necessary. The weight of drilling fluid used varies from 8⅓ pounds, clear water, to 14 pounds per gallon.

Mud-disposal system.—City ordinance rules prohibit permitting the escape of rotary mud into the streets or storm sewers. The small space available on many town-lot leases requires that the reserve pit be of small capacity, and that the space occupied by the reserve pit during drilling be used for the lease tank battery on completion of the well. To dispose of the reserve and excess drilling mud the Phillips Petroleum Company built a pipe line to serve leases in Sections 3, 10, 15, and 22, T. 11 N. R. 3 W. The main line consists of 3¼ miles of 4-inch line pipe. Mud is emptied into North Canadian River near the south line of Sec. 3, T. 11 N. R. 3 W. Other operators in the area served are charged a small amount for mud disposed of through this line.

Sample catching.—By the time the discovery well at Oklahoma City was drilled, experience in other fields in the Mid-Continent area, principally Seminole, had shown that a rotary drillers' log was of little value for geological purposes. It had become the practice with most operators to assign one geologist or more to a wildcat well to insure the catching of good samples of the drill cuttings and the coring of possible oil- and gas-bearing horizons. The discovery well at Oklahoma City was handled in this manner. Following this precedent samples were carefully saved from the surface down on the first wells drilled in the field. A study of the cuttings from these wells showed that the first reliable and easily recognized key beds for structure mapping were found below 3,000 feet. For this reason, coupled with the facts that as the number of drilling wells increased it was impossible for the geologists working in the field to supervise personally the catching of cuttings and it became necessary to rely on drilling crews, samples of the cuttings were not saved generally above 3,000 feet in depth. The formations above this depth were drilled so rapidly that it was impossible for the drilling crews to catch samples at short intervals. It then became the practice

to assign geologists a number of wells to supervise the catching of cuttings by the drilling crews. At the present time the drilling crews are required to catch samples of the cuttings and very little supervision is necessary. Some operators place a clause in their drilling contract requiring the furnishing of accurate samples.

Some of the small operators have not caught samples on their wells above 5,000-6,000 feet, but out of 903 wells drilled in the field there are less than five on which samples of the Lower Pennsylvanian and pre-Pennsylvanian sections have not been caught, washed, examined, and filed.

Sampling of rotary cuttings in the Oklahoma City field has been accomplished on at least 90 per cent of the wells by settling devices, the most common of which is a wooden box through which part of the return mud is diverted from the flow line. Removable baffles in the wooden flow trough have proved very satisfactory at some wells. Swedge nipples welded into the bottom of the steel flow line have been used. A driller in the Oklahoma City field devised a steam jet for such a catcher which delivers the sample from the swedge nipple to a baffle box on the derrick floor. This method is very efficient, but is not in general use. Another device occasionally used is a screen bag which strains out a sample from part of the returns. Samples of the cuttings are usually taken at 10-foot intervals in the upper part of the section and 5-foot intervals in the lower part.

Crooked-hole tests.—Available data show that systematic records of crooked-hole tests have been kept on at least 492 of the wells drilled in the Oklahoma City field. In addition there have been numerous tests run by contractors on their own initiative of which there is no record. Two operators have used the Halliburton acid-bottle method exclusively. At the present time the Driftmeter is used for most tests. Below 4,000 feet the Kinley acid-bottle method is satisfactory, as very little time is lost in taking the readings. The Syfo Clinograph has been used extensively, but considerable difficulty has been experienced below 3,500 feet, due to leakage of the outside shell.

Results of these crooked-hole tests show that most Oklahoma City wells are comparatively straight. Records on 419 wells show an average maximum angle of deviation from the vertical of 4.7°. The maximum recorded angle of deviation in a completed well is 16.5° at 3,500 feet. The last reading in this hole showed an angle of 8° at 5,500 feet. The total vertical correction was 87.10 feet. However, it is required by most operators that a hole be straightened if the deviation at any time reaches

a specified maximum angle, usually ranging from 5° to 10°. There have been ten holes plugged back and redrilled to straighten. There have been three holes plugged back to the surface and the rig skidded because of crooked holes. Most of these 13 wells were more than 5° off vertical at less than 2,000 feet.

Figure 19 shows graphically the depths of maximum deviation for 419 wells drilled in the field. The depths at which wells had their max-

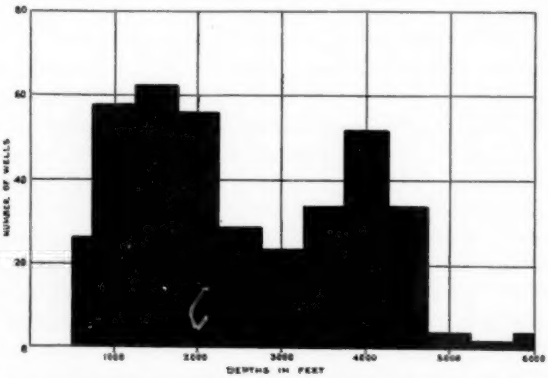

FIG. 19.—Maximum deflection diagram, showing depths at which most wells had maximum angle of deflection from vertical.

imum deviation are from 1,000 to 2,000 feet with the greatest number at 1,500 feet, and from 3,500 to 4,500 feet with the greatest number at 4,000 feet. Sixty-two wells had their maximum deviation at 1,500 feet and 51 at 4,000 feet.

There is no doubt that the technique of drilling straight holes has been developed more in the past 2½ years in the Oklahoma City field than during any other period since the use of rotary tools became general. Some data gathered from one of the major operators show the steps in the evolution of straight-hole drilling in the Oklahoma City field. This company, on April 2, 1930, let the contract for its first well in the field, allowing 10° as the maximum deviation from the vertical. Before this well was 3,500 feet deep it became evident that the hole was crooked and that 10° was too large a deviation to allow. A directional survey of the well was taken at considerable expense to the company. This survey is shown in Figure 20. It was found that the hole was spiralling in a clockwise direction, the direction of the drill pipe rotation. After this

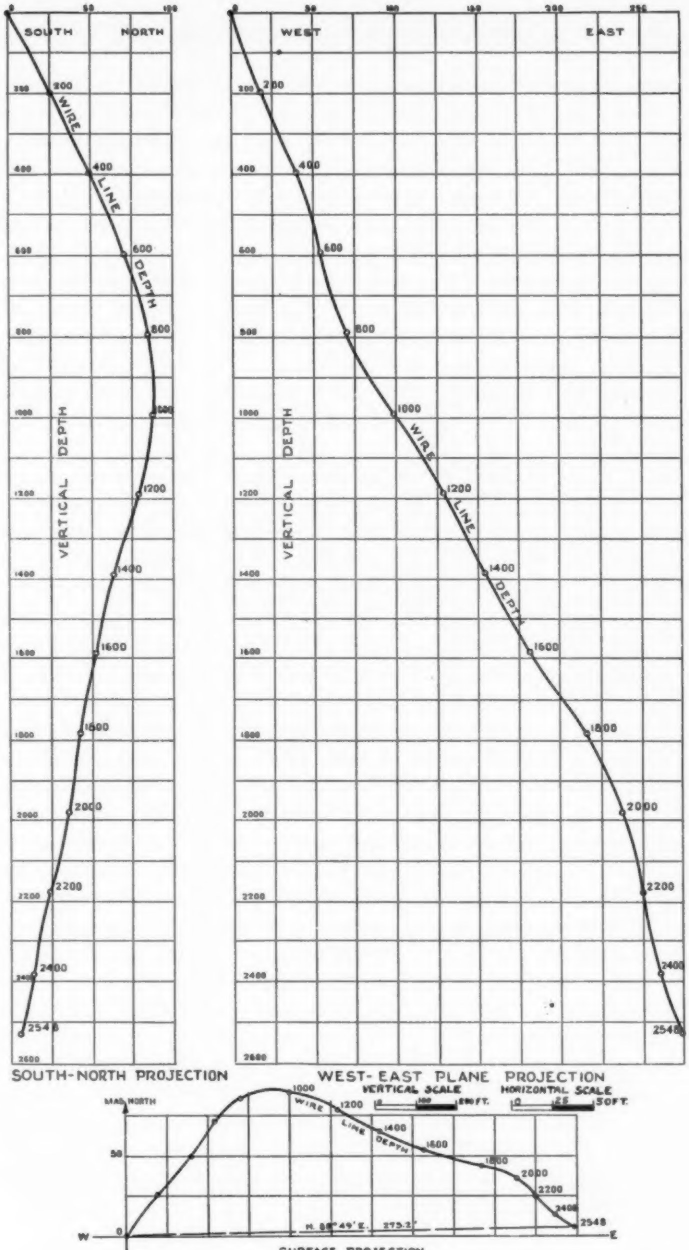

Fig. 20.—Crooked-hole directional survey, showing deviation from vertical in north-south and east-west planes; also surface projection of path of hole; Oklahoma City field, surveyed by Sperry-Sun Well Surveying Company.

survey the rig was skidded and a new hole was commenced, the company losing the hole and paying the expense of skidding the rig. The next three contracts that were let (April 29, 1930), had 7° as the maximum angle of deviation. On July 2, 1930, the maximum angle allowed was lowered to 6°. It remained at this figure for the drilling of 31 wells. On March 2, 1931, the maximum angle of deviation allowed was reduced to 4°, which is the present figure.

The drilling contractors at first were opposed to the lowering of the maximum angle of deviation permitted, as it was thought the narrow limit allowed would retard drilling. Actual data show that holes drilled with only 4° maximum deviation allowed have required less drilling time than holes in which a larger angle was permitted. Data from the company show:

1 well allowed	10°	Drilling time 77 days
3 wells allowed	7°	Drilling time 99 2/3 days average
31 wells allowed	6°	Drilling time 71 9/10 days average with one 9 5/8-inch flow string
18 wells allowed	4°	Drilling time 66 2/10 days average with five 9 5/8-inch flow strings

Drilling time.—Early wells in the field required approximately 100 days of drilling time. The present average drilling time is about 65 days. The best run in the field was made on Anderson and Kerr's Metcalf No. 1, Sec. 15, T. 11 N., R. 3 W. This well was completed at a total depth of 6,570 feet in 36 days of drilling time, or an average of 182 feet of hole drilled per day for the entire depth. Several wells in the field have required less than 45 days drilling time, including fishing jobs.

Formation coring.—In the early development of the field considerable coring was done. In a few of the first wells drilled the gas- and oil-bearing sands of the Pennsylvanian were cored. Some coring was done in the Arbuckle limestone, and extensive coring was done in the lower Simpson section. A total of approximately 12,852 feet have been cored,[1] of which 7,038.2 feet were recovered, with an average of 54.6 per cent. Hard formation core heads have been used almost exclusively. The chief difficulty has been to get on bottom before the core barrel filled with cavings. Soft unconsolidated sands have not generally been recovered by coring. The core barrels used have taken cores 1⅜, 2⅛, and 3⅛ inches in diameter. As soon as the details of the pre-Pennsylvanian stratigraphy were known it was not necessary, excepting in a few

[1]Rudolph Brauchli, Anderson-Pritchard Oil Corporation, Oklahoma City; personal communication.

wells, to core the producing horizons. It became the practice with some operators to set the flow string of casing at the top of the horizon to be produced, then to drill into it. With the upper formations cased off, good uncontaminated samples of the beds below the casing were secured.

Completion methods.—A few of the first wells were drilled with rotary to the top of the Arbuckle limestone, then drilled in with cable tools. The large gas volumes at high pressure caused hazardous fishing jobs, which resulted in delay in completion and increased cost. It soon became the general practice to drill the wells to the total depth with rotary tools. Some operators drilled through the producing formation before setting the flow string. Others set the flow string first in the top of the Arbuckle or Simpson and then drilled in with smaller rotary. The advantages of drilling the producing formation before setting casing are: (1) that the various sands can be examined and the casing set through the upper sands which contain large volumes of gas and little oil; (2) that a larger diameter hole is drilled through the producing horizon; (3) the danger of damaging the flow string is nearly eliminated, as little drilling is done through the pipe.

The advantages of setting the pipe first and drilling in through the flow string are: (1) that better samples of the formation being drilled are obtained and consequently more accurate knowledge is secured; (2) there is less time for the drilling mud to remain on the sand before completion with danger of partly mudding it off; (3) there is less danger of losing the hole with the upper formations cased off.

In drilling the producing horizons it has been the policy of one operator to use very heavy mud, up to fourteen pounds per gallon in weight. This was thought to be the best prevention for blow-outs and wild wells. Other operators, believing that heavy, consequently thick muds, become gas-cut quicker, and are more hazardous than very thin muds or even clear water, drill in with light mud or water.

Wild wells.—There have been 18 wild wells in the Oklahoma City field. Only 9 of these were out of control for any length of time. The causes and number of wild wells may be tabulated as follows.

Cause	*Number of Wild Wells*
Blow-outs while drilling	6
Sand cutting while producing	7*
Explosion, or blowing off connections	4
Blow-outs while running casing	1
Blow-outs while testing	1

*After the Mary Sudik No. 1 was brought under control it cut out connections with sand, and is thus placed in both classes. The science of controlling wild wells has developed to the point that now a well can ordinarily be controlled in a few hours after the damaged connections are removed.

Depth and producing formation drilled.—The water table in both the "Wilcox" and lower Simpson sandstones was found slightly below a subsea depth of 5,400 feet in extreme edge wells, early in development. Wells high structurally, encountering only the Kinter sandstone (lowest producing sandstone in the Simpson group) were generally drilled into the "Stamper" zone. Farther out on the flanks of the anticline, where younger Simpson beds were encountered, the general practice was to drill in the Simpson to the Kinter sandstone, if it could be encountered above a subsea depth of 5,400 feet. If the "Kinter" sandstone could not be reached, the well was drilled to a subsea depth considered to be above the water table. When the first wells were drilled in the inner edge of the "Wilcox sand" wedge, the operators were not completely familiar with the pre-Pennsylvanian stratigraphy and drilled their wells through the very prolific "Wilcox sand" into the Simpson sandstone below. There are at present 80 such wells which have the "Wilcox" and lower Simpson sandstones exposed in the same hole.

As indicated on the pre-Pennsylvanian columnar section (Fig. 5), the Simpson formation has been subdivided into five general zones with more or less well defined sand bodies in the basal part of each of these zones. Due to the post-Mississippian truncation of the fold, Pennsylvanian beds are in contact at some point with all of these zones; consequently wells drilled at various points encountered successively higher Simpson formations as drilling progressed outward from the axis of the fold. Many wells drilled into the lower part of the Simpson formation produce from several hundred feet of open hole which includes various parts of the several zones.

Surface connections.—The well-head connections for producing wells in the Oklahoma City field are unique in that Christmas-tree connections are not used. The problem has been to handle large volumes of gas, oil, and sand at high velocity under pressures as great as 2,400 pounds per square inch. The flow string is set on the water string in a vented Braden head. Both strings are clamped down and anchored to the surface pipe and to deadmen set in concrete in the cellar. The flow strings are equipped with three heavy duty master gates operated by extensions at least 50 feet from the well. Each master gate is tied down by wire lines or rotary chains and tightened with turnbuckles. Above the upper master gate, the hook-ups vary somewhat. Some wells are equipped with a sand hog or some kind of small expansion chamber with the outlet in the side. Others have a choke installed above the master gate and an expansion chamber between the choke and the separators.

Two or even four large (7- × 24-foot) separators are required to handle the flow of large wells on initial or potential gauges. Oil goes from the separators to 1,500-barrel settling tanks or direct to the stock tank battery, which consists of from four to eight 1,500-barrel tanks. Gas from the separators goes to gasoline plant gathering lines or is vented.

Completion.—After the producing horizon is drilled and the well connected to separators and tanks the drilling mud is bailed from the hole. Some wells, especially in the "Wilcox sand," have not required bailing. This is explained by the fact that the porous producing horizons absorb the drilling fluid until the hydrostatic column is in equilibrium. The flow of gas and oil into the hole builds up pressure and when the gates are opened the well starts cleaning itself. Until drilling was begun within the city limits, all wells were allowed to clean out over the top. In the residential sections this was not possible and various hook-ups were devised. Essentially all consist of a large separator which separates the mud and water from the gas and oil. The flow in several wells first went through a sand hog set directly above the upper gate. The purpose of the sand hog, Hewgley head, and similar heads is to provide expansion space in order to reduce velocity and prevent eddies or swirls in the flow which would start sand cutting action. Some wells have been completed through chokes. In some cases, especially with large wells, this has not appeared to damage the well. Other wells completed through chokes smaller than 2-inch have not cleaned out thoroughly, and production has been only a small fraction of that from offsets, producing from the same formation, which were cleaned without back pressure and allowed to make sand.

Flow strings.—The flow string in most wells is 6⅝-inch O. D. casing. Seven-inch O. D. casing has been run in some wells, and 27 wells are flowing through 9⅝-inch O. D. pipe. Three operators have run 5-inch flow strings with screen pipe on the bottom set in the producing formation in order to reduce the danger of sand cutting connections. These screen pipes have prevented the well from making sand, but have also cut down the initial production. Various sizes of tubing have been run in wells of small capacity for flow strings.

Proration and potentials.—The Oklahoma City field has been under a stringent proration program almost from the discovery. From September 12, 1929, to January 3, 1931, all wells were allowed a certain number of hours' flow in a period of specified length. From January 3, 1931, to the present wells have been allowed a certain percentage of their calculated Corporation Commission potential, which is twice the 4-hour gauge.

Operation.—Obviously when the allowable production for a well is expressed in hours rather than in barrels, it is the desire of an operator to flow his well at a rate that will produce the maximum amount of oil in the time allotted. Until percentage proration became effective, practically all wells, when on production, were flowed wide open. This method of operation was expensive, dangerous, and inefficient. Additional equipment was necessary to handle wide-open flow, there was constant danger of wild wells from sand cutting, and on most wells the gas-oil ratios were unnecessarily high. Although there is no regulation requiring restricted oil flow or establishing a maximum volume of gas that can be produced with each barrel of oil, present practice, by all except a few small operators, is to produce their wells when advisable through chokes against back pressure.

An inventory of the Oklahoma City field on December 8, 1931, showed the number of wells equipped with solid or adjustable chokes as follows.

	Number Wells	*Type Choke* *Solid*	*Adjustable*	*Per Cent*	*Total Choke*	*Per Cent with Choke*
Total number of flowing wells in the field................	731	115	294	(71)	409	56
Number of "Wilcox" wells flowing...................	281	46	163	(77)	209	74
Number of lower Simpson and "Lime" wells flowing......	450	69	131	(65)	200	44

This tabulation shows that 56 per cent of all flowing wells in the field were equipped with some type of choke.

Some of the wells are equipped with small adjustable chokes in the flow line, and others are equipped with combination flow head and adjustable chokes which are placed directly above the casing and used as a flow head while taking potentials, and later converted to an adjustable flow bean.

Tests that have been made in the Oklahoma City field by applying back pressure to wells producing from the various horizons have shown that back pressure on some wells increases the gas-oil ratio. Some of the wells producing from the lower Simpson sandstones do not respond to the application of back pressure, but wells producing from the "Wilcox sand" ordinarily show good results from choking. A study of field conditions shows that the high gas-oil ratios of some wells have decreased in a short time in gas volume to such an extent that the wells produce

on a comparatively small gas-oil ratio, whereas in other wells the opposite is true. A study of field conditions also shows that there has been a remarkable shifting of gas volume from one well to another.

It was estimated on December 8, 1931, that there were 75 wells in the Oklahoma City field that had a gas-oil ratio in excess of 10,000 cubic feet per barrel of oil. The ratio in a few of these wells is as much as 400,000 cubic feet per barrel. It is impossible to recondition some of these high gas-oil ratio wells in any way or to operate them in any manner so as to reduce the ratio to a low figure. Carefully kept data on a group of 52 wells show that during approximately 6 months of 1931 the results of flowing wells through chokes were: total gain in price of oil by raising gravity with chokes, $38,986; gas saved by lowering the gas-oil ratios through chokes, 1,001,568,000 cubic feet. This gas energy would lift 916,890 barrels of oil. The same operator, on a group of 55 wells, has an average gas-oil ratio of 1,954 cubic feet per barrel when producing through chokes of the size experimentally found most efficient for each particular well. These "best openings" range from ½ inch to 1¾ inches, most of them being about 1 inch. The back pressures when flowing through these openings range from 20 to 1,450 pounds per square inch.

Artificial lift.—Gas lift is being successfully used on wells in the Oklahoma City field. Compressors are three-stage, designed for 1,500 pounds working pressure. Fluid levels are relatively high, approximately 5,000 feet in Arbuckle and 4,500 feet in lower Simpson. Best results have been obtained with tubing submerged from 1,500 to 2,000 feet, or a total lift ranging from 2,500 to 4,000 feet. Kick-off pressures range from 700 to 800 pounds, and working pressures average about 350 pounds.

Pumping in the field has not been thoroughly tested. Wells now pumping have the barrels set near bottom, but fluid levels range from 3,000 to 4,000 feet and it is the opinion of most engineers that these wells are producing by agitation rather than true pumping.

Handling oil.—Large wells and limited pipe-line facilities have resulted in unusual methods of handling oil. Lease storage is usually filled in a short flowing time. It is then necessary to cease production until the oil is moved through one of the pipe lines. On February 1, 1932, the total pipe-line capacity of the field, including tank cars, was 447,000 barrels.

Handling salt water.—In the limestone producing area large quantities of salt water have been produced. The water was first run into ponds and left to evaporate. Evaporation was sometimes hastened by

burning waste gas over the surface of the water. Early in the history of the field a salt plant was built on the Sinclair Oil and Gas Company's Stamper lease by an individual. The plant evaporated between 600 and 800 barrels a day, but was soon abandoned because it was not a financial success.

When the problem of salt water disposal became more serious the Community Pipe-Line Company was organized. An 8-mile gravity line of 20-inch Naylor Spiral Welded pipe, Biturine coated and Victaulic coupled, was laid from the SE. ¼, NW. ¼, Sec. 36, T. 11 N., R. 3 W., to ponds built on waste lands in the South Canadian river bottom. The capacity of this line is 200,000 barrels per day by gravity flow. The line went into operation, March 15, 1931.

Water is collected in ponds in various parts of the field and pumped to the starting end of the line, where it is metered. Each operator using the line is tentatively charged one cent per barrel for salt water transported. This charge is expected to retire the cost of the line in five years.

At the present time one company is disposing of its salt water by pumping it into a well drilled to 1,875 feet and cased to 1,340 feet. This well will take water at the rate of 3,000 barrels per day under a pressure of 700 pounds. Most operators now producing only small amounts of salt water run it into sumps where it is left to evaporate.

Sand produced.—Many wells in the field that produce large volumes of oil and gas, particularly wells in the "Wilcox sand," have produced large volumes of loose sand. Ordinarily this sand, if not too great in volume, is bled from the separators as produced. However, much sand has gone into flow and stock tanks, and by some companies this has been measured, so that some good estimates of the amount of sand produced are available. The first well in the Oklahoma City field to produce any appreciable quantity of sand was the Skelly Oil Company's Hoopes No. 1, producing from the Kinter sandstone, which on initial flow averaged 1,233 barrels of oil and approximately 100 barrels of sand per hour for the first 6 hours.

The minimum amount of sand produced in a short time, of which there is any record, was produced by the Sinclair Oil and Gas Company's Vencl No. 13, SE. ¼, Sec. 31, T. 11 N., R. 2 W., a "Wilcox sand" well which made 685 barrels of sand and 700 barrels of oil in 45 minutes. The maximum measured total amount of sand produced by one well is approximately 5,900 barrels. This particular well was producing from 95 feet of "Wilcox sand." The volume of sand, removed with the oil, would leave a hole in the producing formation, if the hole is assumed

to be cylindrical, slightly more than 21 feet in diameter, and 95 feet in length. Several "Wilcox sand" wells have made 1,500-2,000 barrels of sand in their first 8-hour flow.

It has been calculated that the velocity of flow through the 7-inch casing in a well producing at the rate of 50,000 barrels and 50,000,000 cubic feet of gas per day with 100 pounds back pressure is more than 200 feet per second.

The cutting effect of sand produced with the oil at a high velocity of flow is remarkable. Seven wild wells have resulted from sand cutting out connections. At countless other wells connections have been damaged to the extent that replacement was necessary.

Numerous examples have shown that from the oil production standpoint, it is desirable to produce sand in the initial flows. Wells which produce large volumes of sand initially are almost without exception better oil wells than those that do not.

Mudding off by offsets.—A few wells producing from the "Wilcox sand" have been killed by the migration of drilling fluid through the sand from offset drilling wells. Cotton-seed hulls pumped into a well drilling in the "Wilcox sand" in an attempt to regain circulation, were produced by an offset well. Water and drilling mud from drilling wells are frequently produced by offset producers. A few producing wells that were killed by offset drilling wells came back on production when bailed and cleaned out.

Activity.—The development of the Oklahoma City pool has been conducted in an orderly fashion, exploration being carried outward carefully from the proved limits of production. Due to the serious economic condition in the industry, the small percentage of allowable flow, and the high cost of completing deep wells, there has been little of the feverish wildcatting normally accompanying the development of fields of this size.

Figure 21 shows graphically the number of drilling wells and the average daily production by months, together with the calculated 24-hour potential and the number of producing oil wells. It will be noted that the peak of drilling activity was reached on July 11, 1930, at which time there were 344 active operations in the field. The peak 24-hour potential for the field was 11,086,148 barrels on September 30, 1931. The largest single day's production was 340,562 barrels on October 10, 1931, and the maximum daily average production for a period of one month was 178,963 barrels during December, 1931.

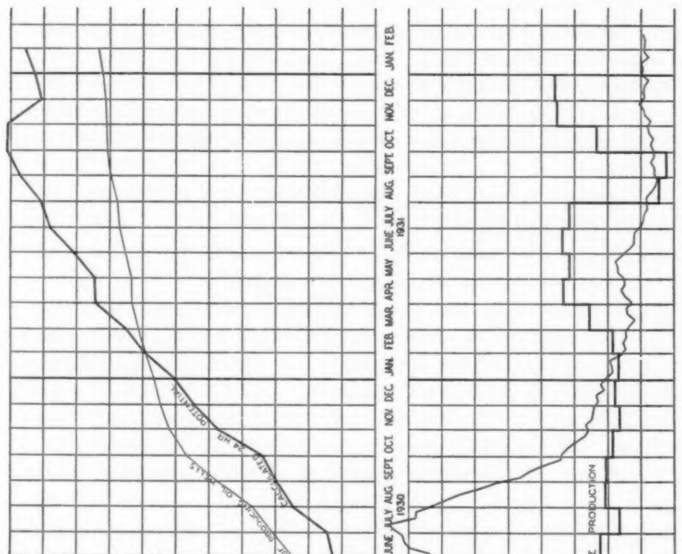

FIG. 21.—Graphs showing calculated 24-hour oil potential, number of producing oil wells, number of drilling wells, and daily average production by months, Oklahoma City field.

WATER ENCROACHMENT

Arbuckle limestone.—Water encroachment in the Arbuckle limestone area was very rapid, the first appearance of salt water occurring in the discovery well on March 4, 1929, just three months after completion. The productive life of wells before the appearance of water rapidly decreased from approximately 100 days for the first group to 20 days for wells completed five months later, and eventually the majority of wells showed water on the initial test or on the first opening after serving the 65-day proration period. Of the 107 producing wells originally drilled in the lime area, only 34 are now capable of commercial oil production and only one has not shown water. Volumes as high as 10,000 barrels of salt water per day were shown by some of the lime wells.

Kinter sandstone.—Water first appeared in the Simpson producing horizons on May 13, 1930, in the Indian Territory Illuminating Oil Company's C. E. Trosper "B" No. 1, NE. ¼, NE. ¼ SE. ¼, Sec. 11, T. 11 N., R. 3 W. From this date the spread of water in the Kinter sandstone was rapid in the central and northern part of the field (Fig. 22). The average number of wells going to water is about 7 per month. Part of this water was unquestionably edge water from the lower edge of the sand, the irregularity of appearance being explained by channeling through the more porous parts of the sand body. The appearance of water in other wells structurally high is difficult of explanation and is possibly due to contamination from some well or wells which penetrated porous water-bearing horizons beneath the main oil horizon. During the early stages of the water spread in the Kinter sandstone zone numerous attempts were made by various operators to plug off water by cementing back. These efforts were almost uniformly unsuccessful, a gauge of their effectiveness being shown by the experience of one operator in plugging back 34 wells with only 7 successful water shut-off jobs. In several of the successful jobs, water reappeared after a short time. The extremely small percentage of allowable flow during most of this time imposed a very serious handicap on efforts to control the spread of water due to inability to keep the well producing long enough to make a satisfactory test of the cement job.

Salt water was first reported in the lower Simpson sandstones above the Kinter on October 12, 1931, in the Anderson-Pritchard Oil Corporation's Keyes No. 1, Sec. 2, T. 11 N., R. 3 W., 17 months after the first appearance in the Kinter sandstone. The slower encroachment in these sands is due to the lower percentage of porosity, and to the later com-

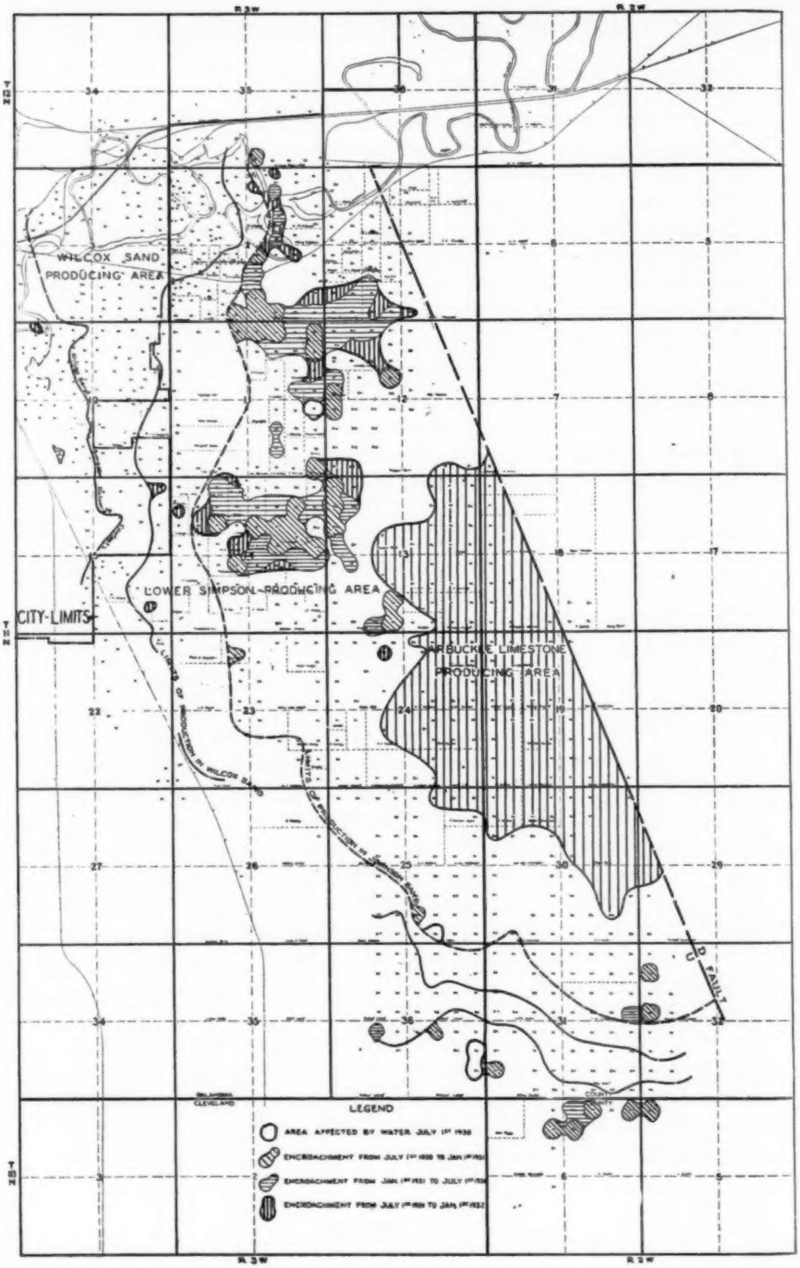

FIG. 22.—Map showing water encroachment in Oklahoma City field. Six-month periods. Width of map: 5 miles.

pletion date of most of the wells in this zone. There are only a few wells showing water in this zone.

"*Wilcox sand.*"—On June 12, 1930, the Sinclair Oil and Gas Company's School Land 67 No. 2, an edge well in the "Wilcox sand," was completed with a salt water content of approximately 35 per cent. This was the first salt water encountered in the "Wilcox sand" and afforded an accurate determination of the original water level in this sand, as the amount of drainage previously had been negligible. The water level at this time was calculated to be 5,425 feet below sea-level for the "Wilcox sand." From time to time other low wells, structurally, were completed in the "Wilcox sand," which either showed water initially or have since started cutting so that an accurate record of the rise of the water in this sand is available. Due to the uniform texture of the sand body, the encroachment up to the present has been very uniform and on February 1, 1932, the level was calculated to be approximately at a subsea depth of 5,370 feet.

Available data indicate conclusively that the original water level in all of the Simpson producing series was virtually the same. At present there are several wells in the Kinter sandstone and numerous wells in the sandstones above still producing clean oil at subsea depths of 5,400 feet or slightly lower. Several early tests either completed or deepened with standard tools in the limestone area encountered water as high as 5,200 feet below sea-level. In some wells, notably the Sinclair Oil and Gas Company's Stamper No. 1, there was conclusive evidence that increased oil production was obtained in lower zones after water had been encountered above. In the well mentioned, the first water was encountered at 6,497-6,499 feet and after deeper drilling the oil production increased from 135 barrels per hour to 445 barrels per hour at a depth of 6,643 feet. Several smaller increases in oil were obtained above this point.

RELATION OF PRODUCTION TO STRUCTURE AND STRATIGRAPHY

Any discussion of the accumulation of oil in reservoirs must of necessity consider the matter of the source of the oil. This point is one on which there are a variety of opinions and on which there is without doubt much still to be learned.

In the opinion of the writers, there is a preponderance of evidence in the Oklahoma City pool to indicate a source for the Ordovician oil indigenous to the Ordovician sediments in and near the area of uplift. Asphaltites at or just above the unconformity at the base of the Pennsylvanian rocks seem to constitute conclusive proof of an appreciable

accumulation of oil in this fold before burial by sediments of Pennsylvanian age. Accumulation doubtless started with the inception of the fold and continued after burial by Pennsylvanian sediments. The fact that large quantities of such materials are not found can be explained by the same processes of erosion and peneplanation which were capable of removing approximately 1,800 feet of rocks from the crest of the fold, leaving only slight traces of detrital or reworked material. The amount of these asphaltites near the base of the Pennsylvanian sediments is not definitely known, but it is significant that in the two wells which are known to have been cored at this horizon, thin laminae of gilsonitic material were prominent just above the contact of Pennsylvanian and Simpson beds. Black asphaltic sandstone of Simpson derivation was found at the contact in one of the early wells. The nature of this sandstone, which was approximately 10 feet thick, indicated prolonged exposure to the air with possibly slight transportation and redeposition.

The source of the oil found in the Pennsylvanian sandstones and the time of its accumulation can not be definitely established. There seems to be little evidence that the oil in the higher Pennsylvanian sandstones migrated up from the Ordovician reservoir. The oil found in the Prue sandstone, in low wells, is thought to be largely derived from the underlying Ordovician sediments, because at many places on the fold the two are in direct contact.

Very little information is available as to the physical characteristics of the oil in the higher Pennsylvanian horizons, due to the scarcity of wells which have tested these horizons where they contained oil. The present production of these sandstones is predominantly gas.

Although it may have been possible for some oil to have reached the upper Pennsylvanian sands by migration from the Ordovician reservoir, the writers are inclined toward an explanation of this accumulation similar to that which would normally occur in any area of favorable structural conditions, even where the older sediments are known to be nonproductive.

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PRORATION AT OKLAHOMA CITY, OKLAHOMA[1]

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ABSTRACT

Geology and petroleum engineering have been important factors in the history of proration at Oklahoma City. Orders and ordinances by State and City have been issued to curtail production and operations only after exhaustive geological testimony. Geologists have presented to the Corporation Commission their ideas concerning the probable extent of the field, ultimate recovery, producing horizons, zoning according to geological formations, effect of proration on the oil sands, gas-oil ratios, water encroachment, migration of oil and gas, drainage areas, gas reserves, and other pertinent fact-finding testimony on which the Commission has since based its proration requirements.

ACKNOWLEDGMENTS

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INTRODUCTION

Many new geological and engineering problems have originated in the Oklahoma City field, and many new legal questions concerning the production and operation of wells have likewise arisen. Only a few years ago such terms as proration, curtailment, zoning, umpire, potential, allowable, overage, underage, and martial law were unheard of in the development and operation of an oil field.

[1]Read before the Association at the Oklahoma City meeting, March 25, 1932. Manuscript received, April 15, 1932.

[2]Geologist, Slick-Urschel, Inc.

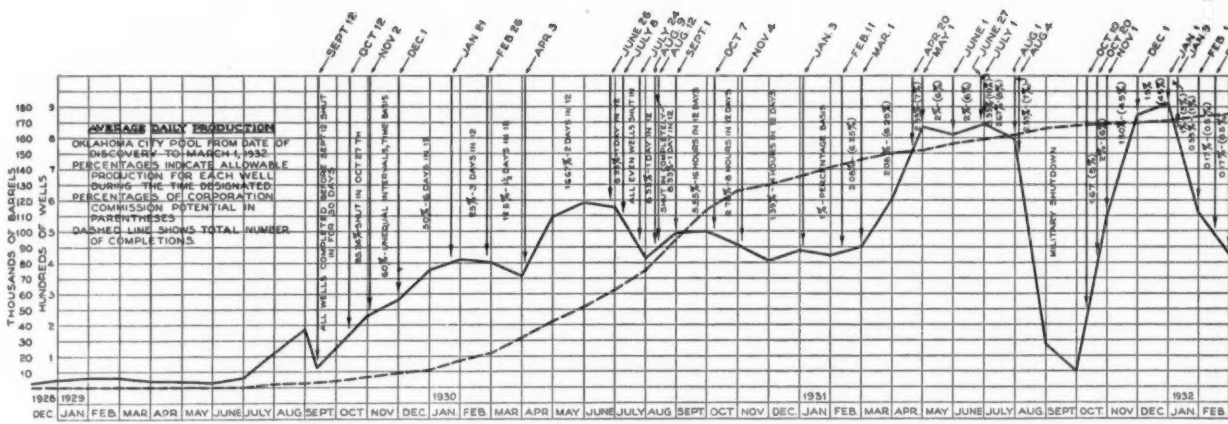
AVERAGE DAILY PRODUCTION
OKLAHOMA CITY POOL FROM DATE OF DISCOVERY TO MARCH 1, 1932.
PERCENTAGES INDICATE ALLOWABLE PRODUCTION FOR EACH WELL DURING THE TIME DESIGNATED.
PERCENTAGES OF CORPORATION COMMISSION POTENTIAL IN PARENTHESES
DASHED LINE SHOWS TOTAL NUMBER OF COMPLETIONS.
THOUSANDS OF BARRELS
HUNDREDS OF WELLS
ALL WELLS COMPLETED BEFORE SEPT 12 SHUT IN FOR 30 DAYS
MILITARY SHUTDOWN
ALL EVEN WELLS SHUT IN
1928
1929
1930
1931
1932

FIG. 1

HISTORY OF PRORATION

The history of proration in the Oklahoma City field is a record of coöperation between the large majority of operators to curtail production through voluntary measures and by strict obedience to orders of legal regulatory bodies. It necessarily involves a study of the causes of overproduction; the necessity for curtailment; operators' meetings; operators' committees; umpires; umpires' committees; committees of geologists and engineers; Corporation Commission orders; city ordinances relating to zoning, the securing of bonds and permits, and the drilling, completing, and producing of wells within the city limits; wild wells and orders resulting therefrom; conservation from a geological and engineering standpoint; and litigation in State and Federal courts.

Both City and State have formulated regulatory measures in attempts to prevent actual and underground waste of gas, oil, and gas energy. They have also attempted to provide safety measures in drilling and operating which would prevent loss of life and property as the result of carelessness or the inexperience of operators. Wild wells, with their attendant fire hazards, have necessitated regulations governing the drilling, completing, and producing of all wells.

The encroachment of the field toward the business and better residential sections of Oklahoma City has been retarded by means of zoning rules. The extension of the U-7, or drilling, zone has been more or less regular as citizens and operators demanded such extensions.

The enormous waste of gas and gas-energy has been alarming and some operators have demanded repeatedly that something be done in the way of conservation. No order of the Corporation Commission has fixed a definite gas-oil ratio. Recently, however, through Order No. 5,738, dated February 16, 1932, permission was given to transfer allowable production from high gas-oil ratio wells to other wells on the same lease. Likewise, some wells have been given greater allowables than others because of water encroachment.

Complete statistical data on drilling and production, and a table of chronological events from the opening of the field to date would present a comprehensive history of proration at Oklahoma City.

Early in the history of the field, the Oklahoma City operators organized and held meetings as various problems arose. Permanent committees were appointed, an umpire was hired, and many recommendations and suggestions were forwarded to the Corporation Commission. Every operator in the field was urgently requested to attend all meetings and participate actively in them.

Restrictions on various phases of operating and producing were at first largely voluntary. Later, the Corporation Commission, after extensive hearings, issued such orders as were deemed advisable and expeident. The failure of the Commission to issue particular orders earlier in the field's development was due partly to disagreement among the operators themselves regarding the correct solution of problems considered, the failure to bring to the prompt attention of the commissioners questions of vital importance, and the inability of the Commission to gather necessary detailed data on highly technical problems from the average testimony at the various hearings.

GEOLOGICAL TESTIMONY

At length, having failed to obtain the desired information, and the operators themselves having failed to agree on certain vital points, the Corporation Commission called together a committee of geologists and engineers to study these problems and to make definite recommendations to the Commission at a special hearing. The following men were appointed and held several all-day meetings: M. J. Kirwan, Indian Territory Illuminating Oil Company; Edw. F. Guidinger, Phillips Petroleum Company; Harold S. Thomas, T. B. Slick Estate; J. R. McWilliams, Skelly Oil Company; E. J. McKee, Wirt Franklin Petroleum Corporation; John E. Van Dall, Sinclair Oil Company; R. W. Brauchli, Anderson-Pritchard Oil Corporation; and R. L. Clifton, Champlin Refining Company.

Recommendations were drawn up and the hearing was held on December 8, 1931. The following changes were proposed by a majority of the members of the committee of engineers and geologists.

1. In order to limit the rate of flow of large wells so as to protect the sand from withdrawals at a too rapid rate, it is recommended that all wells in the Oklahoma City field which produce from the "Wilcox" sand and which have a Corporation Commission potential of 8,000 barrels (operators' potential, 24,000 barrels), or more, and/or a daily gas volume in excess of 25,000,000 cubic feet shall, except when taking potentials, produce through a choke the area of the opening of which does not exceed the area of a circle 3 inches in diameter.

2. The "Wilcox" sand is probably a more valuable deposit than the Simpson-below-"Wilcox" and should be fully protected from migration of oil or gas from the "Wilcox" into other sands, and should also be fully protected from the entrance of water into the "Wilcox" sand. Therefore, it is the opinion of the committee that whenever there is definite evidence that there is appreciable migration of oil or gas from the "Wilcox" sand into the Simpson-below-"Wilcox" that wells in the area affected should either case off the "Wilcox" sand, or the Simpson-below-"Wilcox" should be plugged

off in combination wells in the area affected. Whenever an individual combination "Wilcox" and Lower Simpson sand well shows 3 per cent or more of water, then the "Wilcox" should be cased off or the Lower Simpson should be immediately plugged off.

3. It is the recommendation of the undersigned members of the committee that the present plan be changed so that all wells in the Oklahoma City field (except "Siliceous lime" wells hereinafter mentioned) that produce 3 per cent or more of water be granted a flat exemption of 200 barrels of oil per day, and that no additional allowable above such flat exemption of 200 barrels of oil per day be given such wells; provided, however, that such water wells whose allowable is normally more than 200 barrels of oil per day may continue to produce on the basis of their potentials rather than on the basis of a flat exemption per day.

With reference to wells producing from the "Siliceous lime" which now have an exemption of 250 barrels per well per day, it is the recommendation of the undersigned members of the committee that the "Siliceous lime" area be given a flat allowable of 7,000 barrels of oil per day, to be allotted to the various wells in a manner to be decided upon by the operators in the "Siliceous lime" area, subject to the approval of the Corporation Commission. If, and when, the "Siliceous lime" area is incapable of producing 7,000 barrels of oil per day, the allowable should be reduced from time to time to such an amount as can be produced.

4. It is estimated that there are at least 75 wells in the Oklahoma City field that have a gas-oil ratio in excess of 10,000 cubic feet per barrel. By shifting the allowable production from these wells to other wells on the lease, it is estimated that as much as two or three billion cubic feet of gas could be saved each month. Therefore, it is recommended that wells having gas-oil ratios in excess of 10,000 cubic feet per barrel, at the option of the owner, shift the allowable production from such wells to other wells on the lease having a gas-oil ratio of less than 10,000 cubic feet per barrel, in accordance with the potentials of such other wells on the lease.

5. It is recommended that the advantages of lease proration as listed herein be incorporated in an order by the Commission, but that lease proration in its entirety be not ordered because of the serious major disadvantages herein discussed.

6. No future "Wilcox" sand well in the Oklahoma City field shall be completed at a greater subsea depth than 5,330 feet, 30 feet above the water level, unless permission is secured from the Conservation Officer of the Corporation Commission. As additional information on the rising water level is obtained, this depth should be amended so as to maintain the same relative distance with regard to the water level as shown above.

RESULTANT ORDERS

Since hearing the recommendations of this committee of geologists and engineers, the Corporation Commission has issued orders allotting "Siliceous lime" wells 7,000 barrels of oil daily, later 6,000 barrels, then 5,000, 4,000, and finally 3,500 barrels, beginning March 16, 1932. The

Commission has also ordered that no "Wilcox" sand well be drilled deeper than minus 5,330 feet, unless excepted by the Chief Conservation Officer of the Corporation Commission. Permission has also been given to transfer production from high gas-oil ratio wells to other wells on the same lease.

The problem of overproduction of certain wells at one time was serious enough to threaten the entire proration program. Some of these wells are still shut in, and have been shut in for months, making up their overages. Underproduction at present has become so acute that a special committee of five has been appointed by the umpire to thresh out a solution to this and other problems. These men are: J. R. McWilliams, Skelly Oil Company; A. V. Hoenig, Indian Territory Illuminating Oil Company; Edw. F. Guidinger, Phillips Petroleum Company; W. U. Paul, Acme Gas and Oil Company; and R. B. Roark, Shell Petroleum Company.

Under present orders (March 16, 1932), "even" wells can produce but 0.7 per cent of the operators' potential (2.1 per cent Corporation Commission potential), plus a 25-barrel exemption for all sand wells and an additional 100-barrel exemption for wells making 3 per cent or more of water. The foregoing committee reported its findings and recommendations to the umpire on March 22, and the umpire in turn made his report to the Corporation Commission on March 28. The umpire's recommendations follow.

1. That wells at Oklahoma City be classified as (a) lime wells, to be allowed to produce a definite amount (3,000 barrels daily at present) as a group; (b) water wells, to have an allowable of 1¼ barrels per 1,000 barrels of net field outlet; (c) minimum wells, to be given a daily allowable of ½ barrel per 1,000 barrels of net field outlet; and (d) potential wells, to include all wells not electing, or not eligible for, the lime, water, or minimum well classifications and to be produced on a percentage basis as at present.

2. That all wells, except those making water, be required to take potentials and that these tests be made every 6 months.

3. That any well be allowed to take a new potential test at any time, on written request to the umpire, but that the new potential shall govern the well's allowable, regardless of results.

4. That, in general, current underproduction be given preference in allocating runs from the field.

5. That both gas and oil potentials be taken at the same time, and that before a high gas-oil ratio well be permitted to shift its allowable oil production to other wells on the same lease, it shall be the duty of the umpire to assure himself that the high gas-oil ratio well is capable of making its allowable production before making the transfer.

6. That operators be permitted to take 58 days of their 65-day shut-down period for each well, after the derrick is up and before the well is drilled, instead of after completion of the well, as at present.

7. That no operator be allowed to recondition a well unless written approval is first granted by the umpire, and that detailed daily reports be filed with the umpire during such reconditioning.

8. That any purchaser of gas from oil wells be required at the special request of the umpire to furnish the daily volume of gas metered from a property or well from which that company takes gas.

Orders incorporating these recommendations of the umpire have not been issued by the Corporation Commission to date, excepting Recommendation No. 6. On April 1 an order was issued containing the various proposals in regard to the 65-day shut-down time as submitted by the umpire.

MILITARY SHUT-DOWN

The rapid decline in the price of oil a year ago resulted in drastic action being taken by Oklahoma City operators and royalty owners. In the early part of July, 1931, with a maximum price of 22 cents per barrel, several operators closed their wells completely. A mass meeting of all Oklahoma City operators and royalty owners was then called for July 10, when resolutions were passed (1) closing all oil wells at Oklahoma City "until the price advances to a point fairly commensurate with the cost of production, not less than $1.00 per barrel"; (2) petitioning the governors of Texas, Kansas, Arkansas, and New Mexico to coöperate by closing wells in their respective states; (3) asking the Corporation Commission of Oklahoma to assist in every way possible in curtailment of production in Oklahoma; and (4) petitioning Governor Murray to close all flush pools in the state.

As a result, on August 4, Governor Murray issued an executive order declaring Martial Law, calling out the National Guard, and ordering military control to close all prorated oil wells. It has been necessary for Lieutenant Colonel Cicero Murray, in command at Oklahoma City, to issue only a few orders: one, opening the field to production, October 10; and another, defining over- and under-produced wells, designating methods for taking potentials, giving time limits for running allowables, providing exceptions for repairing wells, and prohibiting the purchase or transportation of illegally produced oil. With only a single exception, no serious trouble has been experienced by the military authorities.

The laws governing proration as a conservation measure have been upheld in State and Federal courts, but an appeal by the Champlin Refining Company is now (March, 1932), before the Supreme Court of the

United States. Other litigation in the Oklahoma City field is concerned with damage suits and matters other than proration itself.

RESULTS OF PRORATION

Proration, the inevitable result of overproduction, has drastically reduced drilling operations in the field. For many months the major companies have made no locations unless forced to do so by offsets, by legal measures, or by pending city or state orders. As a result of proration, the operator himself has come to see the other fellow's viewpoint. He has been converted to the idea that, though temporarily inconvenienced himself, what is best for all is eventually best for himself, and that his own interests should be subservient to the interests of the majority.

Proration itself is a market stabilizer. It was only because of insufficient proration, chiefly in areas other than Oklahoma City, or no proration at all, that the price of oil dropped to 20 cents a barrel at Oklahoma City. The value of proration as a conservation measure is indisputable. Had there been no systematic curtailment of production at Oklahoma City, millions of barrels of high-gravity oil would have entered steel storage, and possibly other millions run into open or other unsatisfactory storage reservoirs, with their subsequent enormous evaporation losses and fire hazards. With conditions such as enormous pressures, gas volumes, and sand cutting, a drilling war inside the city limits might easily have resulted in a catastrophe for Oklahoma City. Proration has prevented such a war.

The principal argument for proration is the resultant elimination of waste and a greatly increased ultimate recovery. The slow, steady withdrawal of oil, gas, and gas-energy from the "Wilcox" sand has undoubtedly resulted in a more or less uniform elevation of the water table. The recovery from the Oklahoma City field to March 1, 1932, was 92,549,808 barrels, or much less than the total production had there been no proration. On the contrary, the rapid and uneven encroachment of water under a program of hit-or-miss production and the enormous waste of gas-energy in wide-open wells would have lowered the total ultimate recovery by millions of barrels.

Proration is a step toward unit operation of oil pools in Oklahoma. In fact, operators and officials are thinking seriously along such lines at the present time. At a hearing before the Corporation Commission a few months ago, Commissioner Childers expressed himself very clearly as being in favor of enforced unit operation of all future pools in Oklahoma.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 10 (OCTOBER, 1932), PP. 1029-1037, 1 FIG.

GENESIS OF OIL BY HIGH RADIAL AXIAL PRESSURE[1]

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ABSTRACT

This paper gives details regarding high-pressure experiments performed with oil shales from Colorado, California, and Fushun, and bituminous coal from Fushun. The test pieces were subjected to high radial axial pressure under similar conditions. It is a remarkable point that all the tests were conducted without showing any yielding by either fracture or flow, and without any effect of thermal change under high pressure.

In all of the present experiments, liquid oil was generated, and the pressure appears to have had some effects on the solubility of the bituminous matter.

It is generally concluded, judged from the experiments, that the high radial axial pressure (hydraulic pressure) on oil shales and coal at room temperature has quantitatively some importance in the generation of liquid oil from such bituminous rocks.

INTRODUCTION

Pressure experiments on bituminous rocks have been performed, previously, by many investigators, but all the tests were conducted under shearing pressure, so that they yielded by either fracture or flow, representing flowage experiments. But the present experiments were done by radial axial pressure under which the test piece has not been forced into flowage structure, possible shearing pressure being avoided.

Oil shale which had been defined by the present writer[3] contains two kinds of bitumen: (1) petrol-bitumen and (2) coal-bitumen, from which so-called oils (gaseous, liquid, and solid states of hydrocarbon compounds soluble in solvents) may be obtained by certain methods of treatment. Of these two kinds of bitumens, it is the first which is mainly contained in California oil shale and to some extent in Colorado oil shales, and the latter is contained in large amounts in Fushun oil shale and coal and in small amounts in Colorado oil shales. By high radial axial pressure these bitumens in the rocks were converted into oils at room temperature, and were soluble in benzol at temperatures up to the boiling point.

[1]Manuscript received, June 18, 1932.

[2]Department of geology and mineralogy, Faculty of Science, Hokkaido Imperial University.

[3]Kunio Uwatoko, "The Fushun Oil Shale Deposit, Manchuria," *Jour. Faculty of Science, Hokkaido Imperial University*, Ser. IV, Vol. 1, No. 2 (1931), p. 129.

The pressure experiments have been made in the Riehle's testing machine at the Civil Engineering Instutite Laboratory by the courtesy of Professor K. Ogawa, Assistant Professor K. Shingo, and Assistants Ohtani and Hata of the Institute, and the steel apparatus in which the test pieces had been compressed were arranged at the Mechanical Engineering Institute Laboratory under the direction of Professor M. Kujime, at the Hokkaido Imperial University.

The present investigator is greatly indebted to the staffs mentioned for their courtesies during the work.

PREVIOUS WORK

Pressure metamorphism of bituminous rocks has been discussed by many authors. White,[1] Strahan,[2] Fuller,[3] Russell,[4] Moulton,[5] Tarr,[6] and Dorsey[7] mentioned, essentially, the stage of pressure metamorphism of the bituminous rocks, showing their causal connections with the occurrence of oil and gas and with the carbon-ratio theory.

Bailey Willis[8] and John L. Rich[9] also noted the large-scale distillation of petroleum as an incident of mountain-making crustal movement, and showed that many of the oil fields are related to belts of dynamic metamorphism competent to have been the source of the oil.

[1]David White, "Some Problems of the Formation of Coal," *Econ. Geol.*, Vol. 3, (1908), No. 4.

[2]A. Strahan and W. Pollard, "The Coals of South Wales, with Special Reference to the Origin and Distribution of Anthracite," *Mem. Geol. Survey England and Wales* (London, 1908), p. 1; reviewed in *Econ. Geol.*, 1909, by David White.

[3]M. L. Fuller, "Relation of Oil to Carbon-Ratios of Pennsylvanian Coals in North Texas," *Econ. Geol.*, Vol. 14 (1919). "Carbon-Ratios in Carboniferous Coals of Oklahoma and their Relation to Petroleum," *Econ. Geol.*, Vol. 15 (1920).

[4]William L. Russell, "Relation between Isocarbs and Oil and Gas Production in Kentucky," *Econ. Geol.*, Vol. 20 (1925).

[5]Gail F. Moulton, "Carbon-Ratios and Petroleum in Illinois," *Illinois State Geol. Survey Rept. of Investigations*, No. 4 (1925).

[6]Russell S. Tarr, "Oil May Exist in Southeast Oklahoma," *Oil and Gas Jour.* (Dec. 17, 1925).

[7]George Edwin Dorsey, "Present Status of Carbon-Ratio Theory," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 5 (May, 1927), p. 455.

[8]Bailey Willis, "Geologic Distillation of Petroleum," *Mining and Metallurgy*, No. 157 (1920).

[9]John L. Rich, "Generation of Oil by Geologic Distillation during Mountain Building," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 11 (November, 1927), p. 1139.

Experiments on the shearing compression of oil shales and other bituminous rocks have already been carried on by others. McCoy[1] reported that after flowage compression of oil shales globules of oil could be seen in the shale with a hand lens. He also made the forecast that some regions in the Mid-Continent oil fields may contain oil generated in place by dynamic metamorphism of moderate intensity too weak to drive it outward from its source; other regions would contain only such oil as had reached them by secondary migration. Trager[2] stated that the fragments of kerogen in the oil shale were completely stained dark brown. This stain was probably due to liquid hydrocarbons produced during the compression. No appreciable heat was developed during the shearing of the shale. Trager also suggested that the organic matter in the shales was distilled by the frictional heat of molecular displacement, yielding hydrocarbons.

Van Tuyl and Blackburn[3] reported the oil shale cylinder to have yielded to deformation by flowage pressure. But the solubility of the kerogen of the flowed shale was found to be consistently less than that of the original shale. McKee and Lyder[4] reported the result of the investigation of the thermal treatment of the oil shale, stating that the formation of petroleum oil is the result of the decomposition or cracking of the heavy bitumen, and also that the formation of oil from bitumen is a function of both the time and the temperature. Adams and Bancroft[5] reported the results of experiments of shearing compression of several barren rocks in a steel cylinder with pistons, the internal friction in the rocks being examined. Hawley[6] recently reported the detailed results of shearing-pressure experiments on oil shales, stating that additional shearing-pressure tests at room temperature all failed to generate oil, and that the increase of bitumen soluble in solvents is believed

[1]Alex. W. McCoy, "Note on Principles of Oil Accumulation," *Jour. Geol.*, Vol. 27 (1919), No. 4.

[2]Earl A. Trager, "Kerogen and its Relation to the Origin of Oil," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 3 (May-June, 1924), p. 301.

[3]Francis M. Van Tuyl and Chester O. Blackburn, "The Relation of Oil Shale to Petroleum," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 8 (November, 1925).

[4]R. H. McKee and E. E. Lyder, "Thermal Decomposition of Shales," *Jour. Ind. and Eng. Chem.* (July, 1921).

[5]F. D. Adams and J. A. Bancroft, "On the Amount of Internal Friction Developed in Rocks during Deformation and on the Relative Plasticity of Different Types of Rocks," *Jour. Geol.*, Vol. 25 (1917), No. 7.

[6]J. E. Hawley, "Generation of Oil in Rocks by Shearing Pressure," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 4 (April, 1929), p. 303; Vol. 14, No. 4 (April, 1930), p. 451.

due mainly to the finer physical state of the highly sheared shale, rather than to any chemical reactions caused by pressure. He obviously stated the negative results of the shearing-pressure tests to generate oil from bituminous rocks in his conclusion.

Considering the afore-mentioned results of high-pressure experiments on the bituminous rocks, it may be said that all tests were subjected to shearing pressure with flowage fracture. But in the present experiment, the shearing pressure has been avoided, so far as possible, in compressing oil shales and coal.

PREPARATION OF EXPERIMENTS

The test pieces used in the present experiment were oil shales and coal, among which Colorado oil shales near Rulison, and California oil shale at Ventura have both been collected by the present writer in 1927, and Fushun oil shale and coal also collected by him in 1928 and in 1929.

Large blocks of each of the test pieces having been secured, bars of them were sawed into lengths of about 2 inches. These bars were then very carefully reduced to the exact size required, by being ground down in a lathe by means of revolving carborundum wheels of different degrees of fineness, and were finally highly polished. When completed, the columns were of such a size that they would just pass into the steel tubes at room temperature, the tube inclosing the column with a perfect mechanical fit. The column was in each case about 1 inch long and 20 3/16 inches in diameter. Though the column was thus fitted accurately into the tube, it could, by the exertion of a certain amount of pressure, be moved up and down within the tube. In preparation of the test pieces, there were needed two kinds of column specimens: one parallel with the plane of sedimentation of the rocks, the other perpendicular to it.

A longitudinal section of the pressure apparatus is shown in Figure 1, as used in the Mechanical Engineering Institute Laboratory of the Hokkaido Imperial University under the care of Professor M. Kujime. The pressure to which the test pieces were submitted was obtained by a Riehle's testing machine set up in the Civil Engineering Institute Laboratory of the Hokkaido Imperial University. This machine has a capacity of 400 tons.

If all equipments of pressure experiments and test pieces are properly arranged, it is important carefully to clean the test specimen and the pressure apparatus with benzol to remove fatty and oily substances on them before setting them up. When the test piece was put into the apparatus, several round pieces of blotting paper of the same diameter as

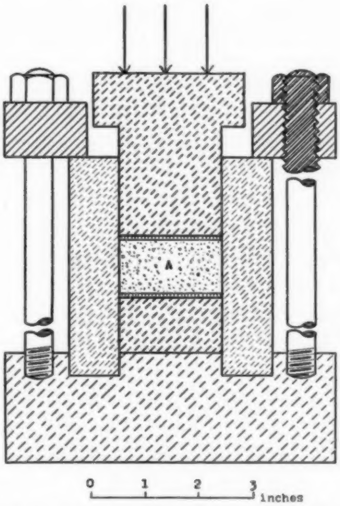

FIG. 1.—Pressure apparatus. Longitudinal section through steel cylinder with plug inserted and enclosing column of test piece. *A*, test piece between packing papers.

the steel tube were packed at both the upper and lower ends of the test specimen to prove liquid oil generated from the bituminous rocks by pressure.

TYPE OF PRESSURE EXPERIMENTS

Previous investigators, mentioned in the foregoing pages, generally have considered the shearing pressure to compress the bituminous rocks, but in the present experiment, the radial axial pressure was required; if it could be obtained, hydraulic pressure would be much better to compress the rocks. That is, the specimen is really compressed by high pressure without deformation of the rocks by fracture and flowage. All surfaces of the test piece were strongly compressed without deformation; that is, the result was almost similar to that of a hydraulic-pressure experiment.

As before stated, it is also one of the remarkable points of the experiments that the time of compression is so long that no thermal change of the test piece by internal friction could be recognized during compression.

Pressure tests of two kinds have been made to determine the effect of compression on the bituminous substances at room temperature.

These include compression (1) perpendicular to the plane of sedimentation of the rock, (2) parallel with it.

EFFECT OF COMPRESSION

The density of the samples, as indicated in Table I, increased a little with a small decrease of their volume. The Colorado oil shales generally are so compact in texture that the volume change was very small by compression. Change of density of the test piece by compression has a close relation to the orientations of the plane of sedimentation of the rock; if the main pressure, axial up and down, is loaded parallel with the plane of sedimentation, the density change is smaller than that of the test piece compressed perpendicular to the plane of it, as is shown in Table I. The density change of Fushun oil shale by compression is the most remarkable among those oil shales tested, although the measurement of that of California oil shale unfortunately failed in part. Fushun coal is so elastic that the volume change by pressure is quickly recovered after being freed from pressure, and its density change after compression is not so large; this is also shown in Table I.

The color of the test piece after compression, generally, became darker on the polished surface as compared with that before compression. Particularly, California and Colorado oil shales showed a strong dark color after compression.

The test piece, after compression, also showed some changes of luster representing more resinous or greasy luster on the polished surface than before compression.

To prove the fluidity of the test pieces of such rigidities as oil shales and coal against high pressure, the ridge of the test piece was partly truncated before compression, but the truncated surface of the specimen which had been free from direct external compression was merely crushed by fracture without showing any flowage structure.

Also, pressure did not cause any recognizable deformation of the sample in texture. Observed either with the naked eye or under a microscope in thin section, it showed its original structure as before compression.

Generation of liquid oil in the oil shales and coal was the most important and remarkable effect of high compression in the present experiment. The fact of generation of liquid oil in the rocks was proved qualitatively by the staining of the blotting paper packed between the test piece and the pressure apparatus. The upper packing paper did not include so large an amount of oil as the lower paper did, but the papers,

TABLE I

SUMMARY OF RESULTS OF HIGH PRESSURE TESTS

Source of Shale and Coal	*Time of Compression*	*Load in Pounds*	*Pounds per Square Inch*	*Density*	*Genesis of Liquid Oil*	*Per Cent Extract from Compressed Shale*	*Per Cent Extract from Uncompressed Shale*	*Difference in Per Cent Extract*	*Increase of Extract in Per Cent*	*Size of Grains in Mesh*	*Remarks*
Colorado velvet shale	......	Nil	Nil	1.590	....	....	0.86	......	......	170	....
Colorado velvet shale	......	Nil	Nil	1.590	....	....	1.05	+0.19	22.09	200	....
Colorado velvet shale	......	Nil	Nil	1.590	....	....	0.86	......	......	170	....
Colorado velvet shale	13+20	300,000	191,083	1.603	Yes	1.59	....	+0.73	84.88	170	*
Colorado velvet shale	13+20	300,000	191,083	1.603	Yes	1.94	....	+1.08	125.58	200	*
Colorado velvet shale	......	Nil	Nil	1.590	....	....	1.05	......	......	200	....
Colorado velvet shale	13+20	300,000	191,083	1.603	Yes	1.94	....	+0.89	84.76	200	*
Colorado velvet shale	13+20	300,000	191,083	1.590	Yes	1.14	....	+0.09	8.57	200	†
Colorado mahogany shale	......	Nil	Nil	1.857	....	....	4.20	......	......	200	....
Colorado mahogany shale	13+20	140,000	89,172	.....	Yes	4.48	....	+0.28	6.66	200	*
Colorado mahogany shale	14+20	400,000	254,000	1.860	Yes	5.55	....	+1.35	32.14	200	*
Colorado mahogany shale	14+20	400,000	254,000	1.858	Yes	4.59	....	+0.39	9.28	200	†
Colorado paper shale	......	Nil	Nil	1.747	....	....	1.32	......	......	200	....
Colorado paper shale	13+20	400,000	254,000	1.748	Yes	2.26	....	+0.94	71.21	200	*
California shale	......	Nil	Nil	.....	....	....	0.53	......	......	200	....
California shale	14+20	400,000	254,000	.....	Yes	0.47	....	−0.06	−11.32	200	*
Fushun oil shale	......	Nil	Nil	1.746	....	....	0.49	......	......	200	....
Fushun oil shale	14+20	400,000	254,000	1.886	Yes	0.57	....	+0.08	16.32	200	*
Fushun coal	......	Nil	Nil	1.213	....	....	1.19	......	......	200	....
Fushun coal	13+20	400,000	254,000	1.219	Yes	2.16	....	+0.97	81.51	200	*

*Compressed perpendicular to the plane of sedimentation of the test specimens.
†Compressed parallel with the plane of sedimentation of the test specimens.

either upper or lower, have been stained very much by the liquid oil generated by pressure along their edges. The stained margin of the round paper looks like a translucent body, such as paraffine paper, while the central part shows rather a semi-translucent appearance with a small quantity of oil.

The quantity of oil generated in the test pieces had also a close relation to the arrangement of the specimen. That is, if the plane of sedimentation of the rock were arranged to be perpendicular to the long axis of the plug of the pressure apparatus, shown in Figure 1, much oil was generated in the rock, while in the other case, if the plane of sedimentation of the same rock were arranged to be parallel with the plug's long axis, the amount of oil generated in the rock was small in quantity.

All the test pieces of oil shales and coal compressed in the present experiment have produced some liquid oil which stained the packing paper. Among the largest of the test specimens, California oil shale produced the largest quantity of liquid oil by pressure.

Soluble organic matter of oil shales and coal after compression was extracted in Soxhlet extractors modified by the present investigator[1] with benzol at any temperature up to its boiling point continuously for 48 hours. As is shown in Table I, the amount of bituminous substance in the oil shales and coal which is soluble in benzol at its boiling point before and after pressure treatment was ascertained. Generally, an increase of extract of soluble matter after compression is recognized in comparison with the amount before compression, except in California oil shale.

The amount of extraction of soluble matter in oil shales increased with the increase of pressure loaded on them, and also it increased with the increase of mesh of grains in mesh.

The test piece compressed perpendicular to the plane of sedimentation of the specimen, as before noted, in the generation of liquid oil, produced much more soluble matter than that of the test piece of the same sample compressed parallel with the plane of sedimentation. Particularly, Colorado oil shales and Fushun coal produced the largest quantities of soluble matter.

It is also a remarkable result that Fushun coal, which contains the most coal-bitumens, produced much soluble matter in benzol by pressure. California oil shale which contains the petrol-bitumens shows conversely negative results of extraction, as is shown in Table I, although

[1]Kunio Uwatoko, *op. cit.*

the liquid oil generated by pressure is recognized in the large quantity stained in the packing blotting paper.

SUMMARY

High radial axial pressure experiments of oil shales and coal have been made to generate oil in the rock without deforming the test piece by fracture and flowage.

Liquid and solid oils produced in the rocks which largely contain either coal-bitumen or petrol-bitumen, are recognized as the effect of high compression.

The amount of oil generated in the rock has a close relation to the intensity of pressure, showing the increase of amount of oil with the increase of pressure loaded on the test piece.

The quantity of oil generated in the rock has also a close relation to the arrangement of the test piece. That is, if the plane of sedimentation of the rock is arranged perpendicular to the orientation of the axial pressure, up and down, a large amount of oil is generated in the rock; while, if the plane of sedimentation of the same rock is placed parallel with the orientation of the axial pressure, the amount of oil generated in the rock is small in quantity.

The amount of oil extraction increased with the increase of mesh of grains in mesh.

The density of the specimens increased a little with a small decrease of their volume as an effect of compression.

The color of the test piece after compression, generally, became darker on the polished surface, and it showed some changes in luster, having a more resinous or greasy surface in the polished specimen.

It is said, on the basis of the results of the experiments here described, that the axial pressure is greater than the radial pressure in intensity.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 10 (OCTOBER, 1932), P. 1038

GEOLOGICAL NOTES

RULE OF DENSITY OF OILS

Frequently the high density of oils is mentioned as an argument against migration. On examples in Roumania, I was able to show[1] that the specific density of paraffine oils decreases in an upward direction (toward the surface), and density of naphthene oil increases in an upward direction; exceptions are found in the case of paraffine oils affected by late tectonics; in the case of naphthene oils small filtered deposits may occur on the top of deposits of heavy oil. No relation exists between age of reservoir rock or intensity of tectonics or thickness of burying, and the character of oils. Naphthene oils are found always above paraffine oils; they are related to recent or ancient surfaces. I conclude that the naphthene oils are formed under an agency working down from the surface.

The old age of many deposits in the United States makes differences possible; for example, oils might be changed to naphthene oils down to the source rock. But below heavy naphthene oils in younger deposits I should expect first lighter naphthene oils, then below an unconformity a series of paraffine oils increasing in density with depth.

In Roumania, naphthene oils contain no high molecular paraffines, though paraffine oils contain such paraffines. It is, therefore, easily possible to differentiate both kinds of oil by the temperature of congelation.

KARL KREJCI

SUN YATSEN UNIVERSITY
CANTON, CHINA
July 26, 1932

WATER ENCROACHMENT IN BARTLESVILLE SAND POOLS OF NORTHEASTERN OKLAHOMA AND ITS BEARING ON EAST TEXAS RECOVERY PROBLEM

CORRECTION

In the September *Bulletin*, page 888, in D. R. Snow's paper "Water Encroachment in Bartlesville Sand Pools of Northeastern Oklahoma and Its Bearing on East Texas Recovery Problem," the last figure in the ninth line should be 800,000,000.

[1] "Geochemie der Erdöllagerstätten," *Abh. prakt. Geol.*, Vol. 20 (Halle, 1930).

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 10 (OCTOBER, 1932), PP. 1039-1044, 1 FIG.

DISCUSSION

TIME-EQUIVALENT VERSUS LITHOLOGIC EXTENSION OF FORMATIONS

The invention of a suitable nomenclature for observed facts has been a vital problem in all natural sciences. Important discoveries in many fields of investigation have followed directly upon the adoption of a more representative and revealing system of names than the one previously used. There is no reason to suppose that the science of stratigraphy will be an exception. On the contrary, the rapid accumulation of detailed information, due to the intensive geological field work of the past two decades, has in some regions created a situation which demands that the awkwardness of existing stratigraphic nomenclature be remedied.

Since various shades of meaning are attached to well known formational names, stratigraphers unfortunately speak a confusing language. The difficulty is not, in the writer's opinion, to be attributed to the inadequate definition of formations, but rather to a difference in the methods by which formations are extended laterally from the type locality. On the one hand, there are geologists who include in a formation only those beds deposited during the span of time represented at the type locality; on the other hand, there are those who include the entire physical or lithologic unit of which the beds at the type locality are a part, regardless of differences in the time interval during which the beds of distinctive lithology were formed. This undesirable situation arises especially when geologists undertake to subdivide the rocks of a sedimentary series in which rapid lateral gradation occurs; for example, gradation from a marine to a continental deposit.

A change of facies from marine limestone and shale to coarse clastic rock occurs in many places. A well known example is found in the Permo-Pennsylvanian sediments north and south of the Arbuckle, Wichita, and Amarillo mountain axis in Oklahoma and Texas. In regions of more uniform strata, the discussion in this paper does not apply with special force. In the Nashville basin, for example, the beds form an isolated and circumscribed outcrop and do not vary notably throughout their extent.

An interesting paper has recently appeared advocating the extension of formations laterally as far as beds of the same age may be traced.[1] The author feels that an unsettled question has thus been presented for discussion and he takes this opportunity to offer a dissenting view.

Pointing the way toward a systematic and simple usage, the carefully phrased and authoritative discussion in the Twenty-fourth Annual Report of

[1] J. E. Eaton, "Standards of Correlation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 4 (April, 1931), pp. 367-85.

the United States Geological Survey may well be brought again to the attention of geologists.[1]

3. *The discrimination of sedimentary formations shall be based upon the local sequence of the rocks, lines of separation being drawn at points in the stratigraphic column where lithologic characters change or where there are breaks in the continuity of sedimentation or other evidences of important geologic events.* It will be impossible to delineate on maps of the scale selected for the atlas sheets the limits of each lithologic change, and the geologist must select for the limitation of formations such horizons of change as will best express the geologic development and structure of the region and will give to the formations the greatest practicable unity of constitution. In determining this unity of constitution, all available lines of evidence, including paleontology, shall be considered. Each formation shall contain between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as for example, a rapid alternation of shale and limestone. When the passage from one kind of rock to another is gradual it will sometimes be necessary to separate two contiguous formations by an arbitrary line. When two formations of closely similar lithologic character are in contact it will sometimes be necessary to depend almost entirely on the contained fossils in separating them. The selection of formations shall be such that they will best meet the practical and scientific needs of the users of the map. In every case the definition of a formation in the folio text should include a statement of the important facts which led to its discrimination and of the characteristics by which it may be identified in the field, whether by geologist or layman.

4. *As uniform conditions of deposition were local as well as temporary, it is to be assumed that each formation is limited in horizontal extent. The formation should be recognized and should be called by the same name as far as it can be traced and identified by means of its lithologic character, its stratigraphic association, and its contained fossils.* (The italics have been added by the author.)

Apparently the committee intended that formations should be physical units.

If it is permissible to amplify the above quotation, the author would add the following. A fossil zone having a certain biological uniqueness should not in itself be called a formation; such a zone may, however, be of assistance in defining a rock unit and in the subsequent tracing of its outcrop. Satisfactory means are at hand for the proper designation of such zones and it is not necessary to confuse them with the physical or lithologic units properly called formations. It would be convenient if geologists would use a biological nomenclature, as some paleontologists have already done, when speaking of strictly biological observations; for, while faunas are distributed in a manner closely related to lithologic units in many places, in others their occurrence is found to be independent of the nature of the enclosing strata.[2]

The age relationships in a depositional province may be determined with accuracy only by careful examination of the physical characteristics of the rock. Knowledge of stratigraphic horizons thus discovered is of scientific value.[3] Those who maintain that a formation should be so defined as to in-

[1]Report of the committee on "Nomenclature and Classification for the Geologic Atlas of the United States," *Twenty-fourth Annual Report of the U. S. Geol. Survey for 1902 and 1903*, p. 23. For a brief history of the development of the present system in use by the U. S. Geological Survey, see T. W. Stanton, "Stratigraphic Names," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 8 (August, 1930), pp. 1070-79.

[2]Interesting contributions to this and similar questions have been made by H. S. Williams, *Bull. Geol. Soc. Amer.*, Vol. 16 (1905), pp. 137-50, and Huxley, *Quar. Jour. Geol. Soc.*, Vol. 18 (London, 1862).

[3]Throughout this paper the words "stratigraphic horizon" will be used as a synonym for "stratigraphic surface" or "bedding surface." Such a surface is assumed to reveal the contemporaneity of deposits more faithfully than any other type of geological fact.

clude all of the strata deposited during a definite interval of time make use of stratigraphic surfaces in the upper and lower formational boundaries. The grouping together of two horizons with the intermediate sedimentary beds is an attempt thus to represent three distinct geological entities by a single name, in spite of the fact that the intermediate strata may laterally replace beds of a different nature in a manner which has no genetic relationship to the horizons. For example, simultaneous deposition in the same basin of sediments from two different sources may result in the accumulation of beds possessing one type of lithology without regard to abrupt changes in the conditions controlling the deposition of the other type.

The lateral extension of a formation on the basis of time equivalence involves at least the implied assumption that the beds so named are a physical unit of importance. It often happens, however, that the lithologic nature of this rock is not the same at different places within the "unit," and the viewpoint which permits the strata to be given a single name throughout the depositional province may have no basis in reality. Furthermore, in some places this procedure has resulted in undue emphasis on the thickness of a formation at the type locality; the average of a large number of thicknesses may be quite different if the measurements are taken from the entire depositional basin in which the physical unit occurs. Needless to say, the extension of formational units solely on a "time" basis conflicts with a physical or "lithologic" system. This conflict has produced much confusion in the past, and is still retarding the progress of stratigraphic research in the Southwest.

In regions where lithologic relationships change rapidly along the bedding it seems well to insist that all formations which are of less than series rank shall be recognizable physical units. Where physical uniqueness disappears a formation should be limited; otherwise the field geologist's knowledge of such variations will not be transferred to his maps and hence may be lost to science. While Eaton[1] prefers the *time equivalent* extension of formations, because in this way "locally confusing aspects are shown to have orderly arrangement and causes," the author, on the other hand, finds changes of lithology interesting and instructive. They throw light upon the events of the past. Such a practice of extending formations laterally from the type locality as far as beds of equivalent age may be traced, leads to a method of thinking which places the true stratigraphic relations in the background. It emphasizes the unreal. *It is the more unwise, in that it is unnecessary in designating time equivalency.*

Would it not be better for the purposes of stratigraphy if the horizons of importance were named separately from formational units? The adoption of such a plan would, in the writer's opinion, result in a flexible and at the same time a revealing system of nomenclature. The way would then be free for field geologists to map the lithologic units as they occur in nature without a fancied compulsion to make either the top or the bottom of such real units conform to a stratigraphic horizon. By way of illustration, Figure 1 presents in diagrammatic fashion the complex relationship of stratigraphic surfaces and lithologic units in Oklahoma north of the Arbuckle Mountains. Most of the units depicted are bounded by many different planes of stratification, no single surface continuing at the contact for more than a short distance.

[1] *Op. cit.*, p. 383.

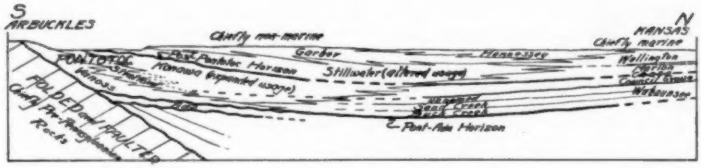

FIG. 1.—Diagrammatic cross section showing complex relationship of stratigraphic surfaces and lithologic units in Oklahoma north of Arbuckle Mountains.

This cross section illustrates the increased emphasis on stratigraphic horizons which the author advocates for sedimentary terranes made complex by rapid lateral changes of lithology. The strata shown are largely of an age transitional between that of unquestioned Pennsylvanian and Permian rocks situated in Oklahoma north of the Arbuckle Mountains.

Two prominent horizons are delineated with as much accuracy as published maps afford. The Pont-Ada horizon is easily followed northward on the Oklahoma geologic map to the Kansas state line, where it seems to be the base of the Wabaunsee. The Post-Pontotoc horizon can not be drawn with accuracy in central Oklahoma because of a lack of detailed maps. However, its exact equivalent in the marine section on the north is not far from the position indicated, which is within the Chase formation.

The diagonal zone of interbedded tongues of different lithology extending from the upper Wellington to the base of the Konawa represents the well known change from red-beds at the south to the non-red marine strata farther north.

The horizon at the base of the Council Grove has on paleontological grounds been considered by many to mark the base of the Permian. It is here shown extending southward into the lower part of the Konawa, though it may correspond to a horizon somewhat higher in this formation.

The field geologist who is expected to discover surface structure, is of necessity interested chiefly in a horizon. According to the proposed usage, he would continue to investigate the properties of this surface and would delineate its position on a map by means of a single line just as he has always done. Those interested in lithologic relationships and the geologic history that may be interpreted therefrom, would find the way cleared for mapping these variations without being misunderstood. In this way time and energy could be saved and the usefulness of stratigraphy could be improved. Those favoring the correlation of a formation to include beds of equivalent age can hardly offer the objection that the determination of stratigraphic surfaces is too difficult to allow a practical application of the proposal made in this paper. While it is admittedly a tedious matter in many places, it is nevertheless a problem identical with the one which is theirs in delineating the top or bottom of such a "time-equivalent" formation.

The very detailed nature of the stratigraphic work which has been done in the Southwest has augmented the difficulties encountered in the application of stratigraphic names, beyond those ordinarily met in areas where the units

are thicker and the economic requirements less exacting. Field geologists of this region, in view of their activity in detailed mapping, could render additional service to geology by insisting on the adoption of a more suitable nomenclature than that now in use.

F. A. Melton

University of Oklahoma
Norman, Oklahoma

In three papers, including the one cited by Melton, I have gone to extreme limits in advocating wider recognition of the degree in which sedimentary deposits vary areally, and have repeatedly called attention to the interesting and instructive nature of such variation. It is therefore with bewilderment that I notice Melton's inference that I do not find such variation interesting and instructive. My Figure 1 in the paper which he cites refutes his charge sufficiently without appealing to the text.

I can not conceive of a marine formation as having, areally, any natural limits except the limits of sedimentation. Quoting from my paper referred to:

> If we could see all of a unit deposited in connected seas under one general control, we could nowhere divide it areally. We divide units areally only when we consider one part of them at a time, as in disconnected exposures.

If we see all of a unit which grades from sand on the west to shale on the east, we have one formation, because there is no division poin', but an ever-changing whole. If, however, a middle link has been eroded, we then *seem* to have two formations, one of sand on the west, and one of shale on the east. I consider it unwise to erect formations on such a haphazard factor. One book does not become two books because some middle pages are torn out. Successive formations vertically, if correctly separated, are like separate but related volumes each of which is more or less complete in itself. Each formation considered areally is like a single volume which must be read as a whole if it is to be understood properly.

Melton and others are vague regarding the natural limits areally of their lithologic units. In every case examined by me where a succession has been divided areally into parts, I have noticed that this has been possible only because connecting links have been eroded, overlooked, or different workers have mapped different areas. I am forced to conclude that all alleged lithologic units into which a single blanket is divided areally are inventions of the human mind, as such imaginary units disregard links which, if supplied, would destroy the *appearance* of separate unity, and reveal a gradational whole. The report of the United States Geological Survey quoted by Melton was wise in specifying the use of "all available lines of evidence," and that a formation "should be called by the same name as far as it can be traced and indentified." These two phrases, when combined, tell everything.

The practice of confining a formation to sediments having obvious lithologic similarity areally is a hangover from primitive days in geology before it was realized that sand, shale, and lime successions grade areally one into the other. We are now beginning to realize that unity based on all available lines

of evidence is the road to success in correlation. In California, where a thick shale succession ofttimes grades to one of sandstone in the space of a mile, the former practice which applied local names caused confusion and stagnation. At present, some worker occasionally creates a local shale or sandstone "formation," but most workers follow an ever-changing whole, term local variations what they are—facies, and apply the name formation to recognizable units which cover the general area of the state. Key horizons are relied on heavily. Micropaleontologists have for several years used a number of such horizons independently of formations.

J. Edmund Eaton

North Hollywood, California
July 19, 1932

In reply to the foregoing discussion by Mr. Eaton, I wish to call attention to the fundamental difference between his conception of what a formation should be and the conception which is advocated in this paper, namely, that all formations should be recognizable lithologic units. To recommend that formations be defined in this way was, I believe, the intention of the Committee on Nomenclature referred to. Hence, the statement in paragraph 4 of their report probably has the following significance:

> The formation should be recognized and should be called by the same name as far as *it* (the formation, *not necessarily* beds of the same age) can be traced and identified by means of its litholigic character, its stratigraphic association, and its contained fossils.

At least if this is not the meaning of the committee, then in my opinion it is time that such an interpretation be adopted, for the good of stratigraphy. Mr. Eaton is of course interested in lithologic units, but he does not seem to regard them as sufficiently important to be represented upon maps and named.

Many geologists are familiar with examples of laterally changing lithology in which lenses and tongues of one type of rock disappear somewhat abruptly in the other. However, lateral changes in sediment are not less interesting and instructive, and the study of them is not less valid, if this change is very gradual. Geologic science has a use for the knowledge of such changes and since this information could be placed upon maps without sacrifice of the time-equivalent correlation, I believe it should be presented if it is available.

I am of the opinion that field geologists in general have never rigorously restricted their mapping to recognizable lithologic units and hence that such procedure can not be a hangover from primitive days. Were it true, however, the reader should judge for himself whether or not it would be undesirable for this reason. Certainly, in rapidly changing terranes, stratigraphic horizons deserve more recognition than they have yet received. Strict adherence to the proposed plan may well be a precursor of better times when present-day confusion in the meaning of formational names shall have been eliminated.

F. A. Melton

The University of Oklahoma
Norman, Oklahoma

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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REVIEWS AND NEW PUBLICATIONS

Earth History, by LUTHER C. SNIDER. The Century Earth Science Series, The Century Co., New York, 1932. Royal octavo, 675 pp., 300 illustrations, index; 4 sections, 30 chapters.

This comprehensive treatise on geology by an eminent petroleum geologist should be welcomed by the elementary student, and especially by the lay reader, for it opens an entirely new door to an understanding of the earth on which we live and our fellow inhabitants. The subject is treated everywhere as history, descriptions of physical processes are subordinated to the march of time, and theories and hypotheses are discussed only as they pertain to events. The result is a generalized, preliminary view of geology as a whole.

Section I, The Book of the Earth, discusses materials and processes, keys to earth history, the earth time scale, cycles of earth history and the nature of borderlands, basins, and troughs. The reader is introduced to the materials in the earth, the nature and use of fossils, various methods of estimating time, the conventional time divisions, and a very illuminating synopsis of earth history on the basis of cycles.

Section II, The History of the Continents, begins with the early Paleozoic, progressing through the Pleistocene, then discusses the pre-Cambrian, and theories of earth origin, mountain making, and climate.

Section III, The History of Living Things, discusses the various forms of life, ending with chapters on life cycles and changes in living things.

Section IV, Man and Earth History, covers minerals, earthquakes, volcanic eruptions, the meaning of scenery, the development of earth sciences, et cetera.

The great number of unusually good illustrations go a long way in helping to tell the story of earth history. Photographs of existing animals, particularly the little known ones, give the reader a better comprehension of the strange creatures of the past.

ROBERT H. DOTT

TULSA, OKLAHOMA
September 5, 1932

"Structure Contour Map of the Montana Plains." By C. E. DOBBIN and C. E. ERDMAN. *United States Geological Survey*, 1932.

This map shows, with a contour interval of 250 feet, the structure of Montana east of the Front Range, including the north end of the Big Horn uplift and the mountain ranges, such as the Big Snowies and the Judiths, that lie out in the plains area. It shows all oil and gas fields, and all, or practically all, of the wells drilled outside the producing fields. It also shows all known exposures of igneous rocks. Some of the mapping is perforce rather broadly

generalized, but on most of the map the amount of accurate detail presented is surprising and gratifying.

Such a map brings out in striking fashion the relationships between major uplifts and the minor structural features in which the oil geologist is primarily interested, and suggests many areas in which further search might be made for such structures. It should form part of the basic equipment of anyone engaged in oil geological work in Montana.

To this reviewer it seems that in maps of this type the United States Geological Survey could find a field of maximum usefulness to the oil industry. It is to be hoped that similar maps of Wyoming, Colorado, and other States may be forthcoming.

MAX W. BALL

DENVER, COLORADO
August 24, 1932

RECENT PUBLICATIONS

AFRICA

"The Geology of the N'Changa District, Northern Rhodesia," by Gerald Christopher Arden Jackson. *Jour. Geol. Soc. of London* No. 351 (London, England), Vol. 88, Pt. 3 (August, 1932), pp. 443-515; 6 figs., 1 map.

CALIFORNIA

"Recent Developments in the Kettleman Hills Field," by H. V. Dodd. *California Oil News* (San Francisco), Vol. 17, No. 1 (July, August, September, 1931), pp. 5-44; 13 pls., 4 tables.

GEOPHYSICS

"The Effect of Geophysics on the Development Hazard in Gulf Coast Oil Fields," by E. E. Rosaire and M. E. Stiles. *Econ. Geol.*, Vol. 27, No. 6 (September and October, 1932), pp. 523-32; 2 figs., 5 tables.

KANSAS

Map of the Oil and Gas Fields of Kansas, by *Kansas Geol. Survey* (Lawrence). The oil fields are shown in green, gas fields in red. The principal oil, gas, and gasoline pipe lines are likewise shown. A list of the oil and gas fields, by counties, is printed beneath the map. Scale: 1:1,000,000. Map dimensions, 13 × 26 inches. Price, $0.25.

KANSAS AND OKLAHOMA

"The Burbank Sand of Kansas and Oklahoma," by Gene Weirich. *Oil Weekly* (August 22, 1932), pp. 25-26, 28; 3 figs.

UNITED STATES

Oil and Gas Fields of the United States, prepared by G. B. Richardson *et al.* *U. S. Geol. Survey* wall map on scale of 1 inch = 40 miles. Oil and gas legend in two colors. Shows fields, pipe lines, and refining centers. Size, 48 × 77 inches. Price, $1.00.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 10 (OCTOBER, 1932), PP. 1047-1057

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Earle Newton Armstrong, Amarillo, Tex.
J. V. Terrill, Archie R. Kautz, Ira H. Stein

Felix A. Vogel, Dolgeville, N. Y.
Kirtley F. Mather, Virgil R. D. Kirkham, Edward D. Lynton

FOR ASSOCIATE MEMBERSHIP

Abdullah Khan Dashti, Teheran, Persia
Hugh D. Miser, Julian D. Sears, Philip B. King

FOR TRANSFER TO ACTIVE MEMBERSHIP

Millard B. Arick, McCamey, Tex.
J. Ben Carsey, Sidney Powers, J. F. Hosterman

CERTIFICATE OF INCORPORATION OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

KNOW ALL MEN BY THESE PRESENTS, That we, Charles E. Decker, Max W. Ball, and Charles M. Rath, being all persons of full age and citizens of the United States, desiring to form a corporation in pursuance of the provisions of Sub. Div. XII, Chapter XXXVIII, Compiled Laws of Colorado, 1921, into which corporation an existing unincorporated association known as THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS may be merged, do hereby make, execute, and acknowledge, in duplicate, this certificate in writing of our intention so to become a body corporate under and by virtue of said laws, which certificate, when filed with the secretary of state of the state of Colorado, shall constitute the articles of incorporation of our said corporation, and we do certify as follows:

1. The corporate name and style of our said corporation shall be the name now belonging to the aforesaid unincorporated association, that is to say, THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS.

2. The objects and purposes for which this corporation is formed are to promote the science of geology in general, but more especially with reference

to its application to the discovery and production of petroleum and natural gas; to promote the technology of petroleum and natural gas; to foster a spirit of scientific research among its members; to maintain a high standard of professional conduct on the part of its members; to protect the public from imposition by inadequately trained or unscrupulous persons; and to promote social intercourse among its members.

In order to accomplish its objects and purposes, the corporation shall have power to hold meetings for social intercourse and the reading and discussion of professional papers; to circulate among its members, by means of publications or otherwise, the information obtained by this or other means; to provide for the organization and continuation of subordinate branches, either within or outside of the state of Colorado, and either within or outside of the United States of America; to hold meetings of its members, and of its managers, either within or outside of the state of Colorado, and either within or outside of the United States of America; to have offices outside of, as well as within, the state of Colorado; to construct, maintain, buy, own, sell, and to rent from others, or to others, such buildings and offices as may, to the executive committee of the corporation, appear desirable in order to accomplish any of its objects and purposes; to provide what qualifications shall be necessary for membership; to provide a classification of membership into two or more classes and the conditions to be attached to each class; to provide the method of electing members; to admit or exclude any person; to expel any person from membership; to provide the conditions under which membership will be forfeited; to provide that membership may be forfeited for non-payment of dues without giving of notice; to provide, and to aid in providing, such entertainment, from time to time, as to the executive committee may appear desirable; to make such prudential by-laws as its members may deem proper in order to accomplish the objects and purposes of the corporation, which by-laws may be divided into two parts, one part to be known as the "Constitution" and the other part to be known simply as "By-Laws," either of which may be adopted, amended, or repealed in accordance with the provisions thereof; and to do any and all other things, and to take any and all other steps, which may be lawfully done or taken by corporations organized under said Sub. Div. XII.

3. Unless its existence be sooner terminated, our said corporation is to exist for the term of twenty (20) years, and may renew its existence at the expiration of said term.

4. The affairs and management of said corporation are to be under control of five managers, to be known collectively as the executive committee, comprising such officers as by the constitution are from time to time made members of the executive committee, and the names of those selected as such managers of our corporation for the first year of its existence, unless the place of any of said managers should become vacant at an earlier time through death, resignation, or otherwise, are:

James H. Gardner
Earl G. Gaylord
Charles E. Decker
Raymond C. Moore
Max W. Ball

The principal office of our said corporation in the state of Colorado shall be located in the First National Bank Building, in the city and county of Denver, and the name of the agent in charge thereof is Max W. Ball.

IN TESTIMONY WHEREOF, We have hereunto set our hands and seals this 21st day of April, A. D. 1924.

(S) MAX W. BALL (*Seal*)
(S) CHARLES M. RATH (*Seal*)
(S) CHARLES E. DECKER (*Seal*)

STATE OF COLORADO
City and County of Denver, ss.

I, Iris Stout, a Notary Public in and for said city and county and state do hereby certify that Charles E. Decker, Max W. Ball, and Charles M. Rath personally known to me to be the persons whose names are subscribed to the annexed and foregoing CERTIFICATE OF INCORPORATION, appeared before me this day in person and acknowledged that they signed, sealed, and delivered the said instrument of writing as their free and voluntary act, for the uses and purposes therein set forth.

Given under my hand and Notarial Seal this 21st day of April, A. D. 1924.

My commission expires March 9, 1926.

(*Seal*) (S) IRIS STOUT, *Notary Public*

CONSTITUTION AND BY-LAWS

(Adopted 1918 and amended 1921, 1922, 1923, 1925, 1927, 1928, 1929, 1930, and 1932)

CONSTITUTION

ARTICLE I. NAME

This Association shall be called "The American Association of Petroleum Geologists," incorporated under the laws of Colorado the 21st day of April, 1924, for a period of twenty (20) years.

ARTICLE II. OBJECT

The object of this Association is to promote the science of geology, especially as it relates to petroleum and natural gas; to promote the technology of petroleum and natural gas and to encourage improvements in the methods of exploring for and exploiting these substances; to foster the spirit of scientific research amongst its members; to disseminate facts relating to the geology and technology of petroleum and natural gas; to maintain a high standard of professional conduct on the part of its members; and to protect the public from the work of inadequately trained and unscrupulous persons posing as petroleum geologists.

ARTICLE III. MEMBERSHIP

Members

SECTION 1. Any person engaged in the work of petroleum geology or in research pertaining to petroleum geology or technology is eligible to active

membership, provided he is a graduate of an institution of collegiate standing, in which institution he has done his major work in geology, or in sciences fundamental to petroleum geology, and in addition has had the equivalent of three years' experience in petroleum geology or in the application of these other sciences to petroleum geology or to research in petroleum geology or technology; and provided further that in the case of an applicant for membership who has not had the required collegiate or university training, but whose standing in the profession is well recognized, he shall be admitted to membership when his application shall have been favorably and unanimously acted upon by the executive committee; and provided further that these requirements shall not be construed to exclude teachers and research workers in recognized institutions, whose work is of such character as in the opinion of the executive committee shall qualify them for membership.

Active members alone shall be known as members.

Life Members

SECTION 2. The executive committee may grant life membership to members who have paid their dues and are otherwise qualified.

Associates

SECTION 3. Any person having completed as much as thirty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, is eligible to associate membership, provided at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing, or shall be engaged in petroleum geology; and any person who is a graduate of an institution of collegiate standing in which he has done his major work in sciences fundamental to petroleum geology or petroleum technology, and who has the equivalent of one year's experience in the application of his science to the study of petroleum geology, shall be eligible to associate membership, provided at the time of his application for membership he shall be engaged in investigations in the broader subject of petroleum geology and technology.

Associate members shall be known as associates.

Associates shall enjoy all the privileges of membership in the Association, save that they shall not hold office, sign applications for membership, or vote; neither shall they have the privilege of advertising their affiliation with the Association in professional cards or professional reports or otherwise.

The executive committee may advance to active membership, without the formality of application for such change, those associates who have, subsequent to election, fulfilled the requirements for active membership.

Election to Membership

SECTION 4. Every candidate for admission as a member or associate shall submit a formal application on an application form authorized by the executive committee, signed by him, and endorsed by not less than three members who are in good standing, stating his training and experience and such other facts as the executive committee shall from time to time prescribe. Provided

the executive committee after due consideration, shall judge that the applicant's qualifications meet the requirements of the constitution, they shall cause to be published in the *Bulletin* the applicant's name and the names of his sponsors. If, after at least thirty days have elapsed since such publication, no reason is presented why the applicant should not be admitted, he shall be deemed eligible to membership or to associate membership, as the case may be, and shall be notified of his election.

SECTION 5. An applicant for membership, on being notified of his election in writing, shall pay full membership dues for the current year and on making such payment shall be entitled to receive the entire *Bulletin* for that year. Unless payment of dues is made within thirty (30) days by those living within the continental United States and within ninety (90) days by those living elsewhere, after notice of election has been mailed, the executive committee may rescind the election of the applicant. Upon payment of dues, each applicant for membership shall be furnished with a membership card for the current year, and until such written notice and card are received, he shall in no way be considered a member of the Association.

Honorary Members

SECTION 6. The executive committee may from time to time elect as honorary members persons who have contributed distinguished service to the cause of petroleum geology. Honorary members shall not be required to pay dues.

ARTICLE IV. OFFICERS AND THEIR DUTIES

Officers

SECTION 1. The officers of the Association shall be a president, a vice-president, a secretary-treasurer, and an editor. These, together with the past president, shall constitute the executive committee and managers of the Association.

SECTION 2. The officers shall be elected annually from the Association at large by written ballot deposited in a locked ballot box by those members, present at the annual meeting, who have paid their current dues and are otherwise qualified under the constitution. Each candidate, when voted for as a candidate for the particular office for which he is nominated, shall be thereby automatically voted for as a candidate for the executive committee for one year, except that candidates for the presidency shall be automatically voted for as candidates for the executive committee for two years.

SECTION 3. No one shall hold the office of president for two consecutive years and no one shall hold any other office for more than two consecutive years except the editor who shall not hold office for more than six consecutive years.

Duties of Officers

SECTION 4. The president shall be the presiding officer at all meetings of the Association, shall take cognizance of the acts of the Association and of its officers, shall appoint such committees as are required for the purposes of the Association, and shall delegate members to represent the Association. He may, at his option, serve on, and may be chairman of, any committee.

SECTION 5. The vice-president shall assume the office of president in case of a vacancy from any cause in that office and shall assume the duties of president in case of the absence or disability of the latter.

SECTION 6. The secretary-treasurer shall assume the duties of president in case of the absence of both the president and vice-president. He shall have charge of the financial affairs of the Association and shall annually submit reports as secretary-treasurer covering the fiscal year. He shall receive all funds of the Association, and, under the direction of the executive committee, shall disburse all funds of the Association. He shall cause an audit to be prepared annually by a public accountant at the expense of the Association. He shall give a bond, and shall cause to be bonded all employees to whom authority may be delegated to handle Association funds. The amount of such bonds shall be set by the executive committee and the expense shall be borne by the Association. The funds of the Association shall be disbursed by check as authorized by the executive committee.

SECTION 7. The editor shall be in charge of editorial business. shall submit an annual report of such business, shall have authority to solicit papers and material for the *Bulletin* and for special publications, and, with the approval of the executive committee, may accept or reject material offered for publication. He may appoint associate, regional, and special editors.

SECTION 8. The officers shall assume the duties of their respective offices immediately after the annual meeting in which they are elected.

ARTICLE V. EXECUTIVE COMMITTEE—MEETINGS AND DUTIES

Executive Committee

SECTION 1. The executive committee shall consist of the president, past president, vice-president, secretary-treasurer, and editor.

Meetings and Duties

SECTION 2. The executive committee shall meet immediately preceding the annual meeting and at the call of the president may hold meetings when and where thought advisable, to conduct the affairs of the Association. A joint meeting of the outgoing and incoming executive committees shall be held immediately after the close of the annual association business meeting. Members of the executive committee may vote by proxy on matters which require a unanimous vote.

SECTION 3. The executive committee shall consider all nominations for membership and pass on the qualifications of the applicants; shall have control and management of the affairs and funds of the Association; shall determine the manner of publication and pass on the material presented for publication; and shall designate the place of the annual meeting. They are empowered to establish a business headquarters for the Association, and to employ such persons as are needed to conduct the business of the Association. They are empowered to accept, create, and maintain special funds for publication, research, and other purposes. They are empowered to make investments of both general and special funds of the Association. Trust funds may be created giving to the trustees appointed for such purpose such discretion as to investments as seems de-

sirable to the executive committee to accomplish any of its objects and purposes, but no such trust funds shall be created unless they are revocable upon ninety (90) days' notice.

ARTICLE VI. MEETINGS

The Association shall hold at least one stated meeting each year, which shall be the annual meeting. This meeting shall be held in March at a time and place designated by the executive committee. At this meeting the election of members shall be announced, the proceedings of the preceding meeting shall be read, Association business shall be transacted, scientific papers shall be read and discussed, and officers for the ensuing year shall be elected.

ARTICLE VII. AMENDMENTS

Amendments to this constitution may be proposed by a resolution of the executive committee, by a constitutional committee appointed by the president, or in writing by any ten members of the Association. All such resolutions or proposals must be submitted at the annual meeting of the business committee of the Association as provided in the by-laws, and only the business committee shall make recommendations concerning proposed constitutional changes at the annual Association business meeting. If such recommendations by the business committee shall be favorably acted on at the annual Association business meeting, the secretary-treasurer shall arrange for a ballot of the membership by mail within thirty days after said annual Association business meeting, and a majority vote of the ballots received within ninety (90) days of their mailing shall be sufficient to amend. The legality of all amendments must be determined by the executive committee prior to balloting.

BY-LAWS

ARTICLE I. DUES

SECTION 1. The fiscal year of the Association shall correspond with the calendar year.

SECTION 2. The annual dues of members of the Association shall be fifteen dollars ($15.00). The annual dues of associates for not to exceed six years after election shall be ten dollars ($10.00); thereafter, the annual dues of such associates shall be fifteen dollars ($15.00). The annual dues are payable in advance on the first day of each calendar year. A bill shall be mailed to each member and associate before January first of each year, stating the amount of the annual dues and the penalty and conditions for default in payment. Members or associates who shall fail to pay their annual dues by April first shall not receive copies of the April *Bulletin* or succeeding *Bulletins*, nor shall they be privileged to buy Association special publications at prices made to the membership, until such arrears are met.

SECTION 3. On the payment of three hundred dollars ($300.00) any member in good standing shall be declared a life member and thereafter shall not be required to pay annual dues. The funds derived from this source shall be placed in a permanent investment, the income from which shall be devoted to the same purposes as the regular dues.

ARTICLE II. RESIGNATION—SUSPENSION—EXPULSION

SECTION 1. Any member or associate may resign from the Association at any time. Such resignation shall be in writing and shall be accepted by the executive committee, subject to the payment of all outstanding dues and obligations of the resigning member or associate.

SECTION 2. Any member or associate who is more than a year delinquent (in arrears) in payment of dues shall be suspended from the Association. Any delinquent or suspended member or associate, at his own option, may request in writing that he be dropped from the Association and such request shall be granted by the executive committee. Any member or associate more than two years in arrears shall be dropped from the Association. The time of payment of delinquent dues for either one year or two years may be extended by a unanimous vote of the executive committee.

SECTION 3. Any member or associate who resigns or is dropped under the provisions of sections 1 and 2 of this article ceases to have any rights in the Association and ceases to incur further indebtedness to the Association.

SECTION 4. Any person who has ceased to be a member or associate under Section 1 or Section 2 of this Article may be reinstated by a unanimous vote of the executive committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member or associate of the Association.

SECTION 5. Any member or associate who, after being granted a hearing by the executive committee, shall be found guilty of a violation of the code of ethics of this Association or shall be found guilty of a violation of the established principles of professional ethics, or shall be found guilty of having made a false or misleading statement in his application for membership in the Association, may be suspended or expelled from the Association by a unanimous vote of the executive committee. The decision of the executive committee in all matters pertaining to the interpretation and execution of the provisions of this section shall be final.

ARTICLE III. PUBLICATIONS

SECTION 1. The proceedings of the annual meeting and the papers presented at such meeting shall be published at the discretion of the executive committee in the Association *Bulletin* or in such other form as the executive committee may decide best meets the needs of the membership of the Association.

SECTION 2. The payment of annual dues for any fiscal year entitles the member or associate to receive without further charge a copy of the *Bulletin* of the Association for that year.

SECTION 3. The executive committee may authorize the printing of special publications to be financed by the Association from its general, publication, or special funds and offered for sale to members and associates in good standing at not less than the cost of publication and distribution.

ARTICLE IV. REGIONAL SECTIONS, TECHNICAL DIVISIONS, AND AFFILIATED SOCIETIES

SECTION 1. Regional sections of the Association may be established provided the members of such sections are members of the Association and shall perfect an organization and make application to the executive committee. The executive committee shall submit the application to a vote at a regular annual meeting, an affirmative vote of two-thirds of the members present and voting being necessary for the establishment of such a section; and provided that the Association may revoke the charter of any regional section by a vote of two-thirds of the members present and voting at a regular annual meeting.

SECTION 2. Technical divisions may be established, provided the members interested shall perfect an organization and make application to the executive committee. The executive committee shall submit the application to a vote at a regular meeting, an affirmative vote of two-thirds of the membership present and voting being necessary for the establishment of such a division. In like manner, the Association may dissolve a division by an affirmative vote of two-thirds of the members present and voting at any annual meeting. A technical division may have its own officers and it may have its own constitution and by-laws provided that, in the opinion of the executive committee, these do not conffict with the constitution and by-laws of the Association. The executive committee shall be empowered to make arrangements with the officers of the division for the conduct of the business of the division. A division may admit to affiliate membership in the division specially qualified persons who are not eligible to membership in the Association. Technical divisions may affiliate with other scientific societies, with the approval of the executive committee.

SECTION 3. Subject to the affirmative vote of two-thirds of the membership present and voting at an annual meeting, and with legal advice, the executive committee may arrange for the affiliation with the Association of duly organized groups or societies, which by object, aims, constitution, by-laws, or practice are developing the study of geology or petroleum technology. In like manner and with like advice, the executive committee may arrange conditions for dissolution of such affiliations. Affiliation with the Association need not prevent affiliation with other scientific societies. Members of affiliated societies who are not members of the Association, shall not have the privilege of advertising their affiliation with the Association on professional cards or otherwise.

ARTICLE V. DISTRICT REPRESENTATIVES

The executive committee shall cause to be elected district representatives from districts which it shall define by a local geographic grouping of the membership. Such districts shall be redesignated and redefined by the executive committee as often as seems advisable. Each district shall be entitled to one representative for each seventy-five members, but this shall not deprive any designated district of at least one representative. The representatives so apportioned shall be chosen from the membership of the district by a written ballot arranged by the executive committee. They shall hold office for two years, their term of office expiring at the close of the annual meeting.

ARTICLE VI. BUSINESS COMMITTEE

There shall be a business committee to act as a council and advisory board to the executive committee and the Association. This committee shall consist of the executive committee, not more than five members at large appointed by the president, two members elected by and from each technical division, and the district representatives. The president shall also appoint a chairman and a vice-chairman, but neither of these need be one of those otherwise constituting the business committee. The secretary-treasurer shall act as secretary of the business committee. If a district or technical representative is unable to be present at any meeting of the committee he may designate an alternate, who, in the case of a district representative, may or may not be a resident of the district he is asked to represent, and the alternate, on presentation of such a designation in writing, shall have the same powers and privileges as a regularly chosen representative. The business committee shall meet the day before the annual meeting at which time all proposed changes in the constitution or by-laws shall be considered, all old and new business shall be discussed, and recommendations shall be voted for presentation at the annual meeting.

ARTICLE VII. AMENDMENTS

These by-laws may be amended by vote of three-fourths of the members present and voting at any annual meeting, provided that such changes shall have been recommended to the meeting by the business committee and provided that their legality shall be determined by the executive committee prior to publication.

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

Frederic H. Lahee, *chairman*, Sun Oil Company, Dallas, Texas
William B. Heroy, *secretary*, Sinclair Exploration Company, New York, N. Y.
Lovic P. Garrett, Gulf Production Company, Houston, Texas
Robert J. Riggs, Indian Ter. Illum. Oil Company, Bartlesville, Oklahoma
R. D. Reed, The Texas Company, Los Angeles, California

GENERAL BUSINESS COMMITTEE

Frank A. Morgan (1933), *chairman*, 856 Subway Terminal Building, Los Angeles, California

C. A. Baird (1933)
Arthur A. Baker (1934)
Albert L. Beekly (1934)
R. Clare Coffin (1933)
Herschel L. Driver (1933)
Walter A. English (1934)
H. B. Fuqua (1933)
Lovic P. Garrett (1933)
S. A. Grogan (1933)
W. R. Hamilton (1933)
J. B. Headley (1933)
William B. Heroy (1933)
Harold W. Hoots (1933)
L. G. Huntley (1933)
Harry R. Johnson (1933)
L. W. Kesler (1933)
R. S. Knappen (1933)
Frederic H. Lahee (1934)
Theodore A. Link (1933)
Joseph E. Morero (1933)
William M. Nichols (1934)
L. W. Orynski (1934)
Ed. W. Owen (1933)
R. D. Reed (1933)
A. H. Richards (1933)
Robert J. Riggs (1933)
S. C. Stathers (1933)
Norman L. Thomas (1933)
J. D. Thompson, Jr. (1934)
H. J. Wasson (1933)
Theron Wasson (1933)
John F. Weinzierl (1933)

RESEARCH COMMITTEE

Alex. W. McCoy (1935), *chairman*, 919 East Grand Avenue, Ponca City, Oklahoma
Donald C. Barton (1933), *vice-chairman*, Petroleum Building, Houston, Texas

R. D. Reed (1933)
W. T. Thom, Jr. (1933)
F. M. Van Tuyl (1933)
W. E. Wrather (1933)
M. G. Cheney (1934)
K. C. Heald (1934)
F. H. Lahee (1934)
H. A. Ley (1934)
R. C. Moore (1934)
F. B. Plummer (1934)
C. E. Dobbin (1935)
A. I. Levorsen (1935)
C. V. Millikan (1935)
L. C. Snider (1935)
L. C. Uren (1935)

REPRESENTATIVES ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

R. C. Moore (1933)
Sidney Powers (1934)

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

M. G. Cheney, *chairman*, Coleman, Texas

Ira H. Cram
B. F. Hake
G. D. Hanna
A. I. Levorsen
C. L. Moody
R. C. Moore

TRUSTEES OF REVOLVING PUBLICATION FUND

Alexander Deussen (1933)
E. DeGolyer (1934)
Frank R. Clark (1935)

TRUSTEES OF RESEARCH FUND

T. S. Harrison (1933)
W. E. Wrather (1934)
Alex. W. McCoy (1935)

FINANCE COMMITTEE

Joseph E. Pogue (1933)
E. DeGolyer (1934)
W. E. Wrather (1935)

PUBLIC RELATIONS COMMITTEE

F. H. Lahee, *chairman*, Box 2880, Dallas, Texas

William H. Atkinson
Donald C. Barton
Ford Bradish
H. A. Buehler
Hal P. Bybee
W. F. Chisholm
Herschel H. Cooper
Carey Croneis
E. K. Soper
Luther H. White
R. B. Whitehead

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

LON D. CARTWRIGHT, JR., consulting geologist of Terrell and Beaumont, Texas, is doing geologic work in Live Oak, San Patricio, Bee, and Goliad counties. He is temporarily located at Twin Oaks Ranch, Dinero, Live Oak County, Texas.

W. B. Lang, U. S. Geological Survey, has recently moved from Roswell, New Mexico, to Washington, D. C.

J. E. BILLINGSLEY, formerly of Charleston, West Virginia, is now located at Newark, Ohio. His address is Box 764.

JOHN J. DOYLE, geologist for the Humble Oil and Refining Company, and formerly located at Beaumont, Texas, is now at Lake Charles, Louisiana. The company recently moved the Beaumont office to Lake Charles.

HOYT RODNEY GALE, formerly of Denver, Colorado, may be addressed at Box 238, Helena, Montana.

JAN VERSLUYS has been appointed professor of economic geology and mineralogy at the University of Amsterdam. His address remains 394 Frankenslag, The Hague, Holland.

LLOYD G. HENBEST, formerly of Sharon, Massachusetts, may now be addressed at the U. S. National Museum, Washington, D. C.

THOMAS A. ALLAN, geologist for the Midwest Refining Company at Russell, Kansas, has moved to 2545 Forest Avenue, Great Bend, Kansas.

J. B. BURNETT, formerly chief geologist for the Lago Petroleum Corporation, Maracaibo, Venezuela, has been made assistant manager for the same company. J. L. KALB, who was formerly assistant chief geologist, is now chief geologist.

W. A. BAKER, chief geologist, Compania de Petroleo Mercedes, S. A., Monterrey, N. L., Mexico, may now be addressed at Huasteca Petroleum Company, Apartado 94, Tampico, Tamps., Mexico.

JOHN M. RIBBLE has moved from Butler, Missouri, to 1523 N. W. 36th Street, Oklahoma City, Oklahoma.

L. C. SNIDER, geologist for Henry L. Doherty and Company, is the author of "Earth History," recently published by The Century Company.

S. F. SHAW, geologist, Tulsa, Oklahoma, has a paper published in the *Journal of the Institution of Petroleum Technologists* for August, 1932, entitled "A Study of Energy in Relation to Production in Oil."

JOHN L. RICH, who has been in Ottawa, Kansas, during the summer, may now be addressed at the University of Cincinnati, Department of Geology, Cincinnati, Ohio.

G. F. KAUFMANN, assistant chief geologist, has changed his address from Compania de Petroleo Mercedes, S. A., Apartado 269, Monterrey, N. L., Mexico, to Huasteca Petroleum Company, Apartado 94, Tampico, Tamps., Mexico.

G. S. HUME, of the Geological Survey of Canada, Ottawa, Ontario, has completed an investigation of the Waterton Lakes area in southwestern Alberta and is now investigating the adjacent Sage Creek and Flathead Valley areas of British Columbia.

SELWYN O. BURFORD, geologist for the Humble Oil and Refining Company, has been transferred from Brenham to Houston, Texas.

GLENN G. BARTLE, who has been on leave of absence from the Junior College of Kansas City during the past school year, has been awarded the degree of Doctor of Philosophy by Indiana University.

JAMES O. G. SANDERSON, consulting geologist of Calgary, Alberta, has been engaged during the summer as engineer on a production investigation of Turner Valley, Alberta, Canada.

F. J. MILLER, of the Arkansas Natural Gas Corporation, has been made district geologist for Mississippi and Alabama, with headquarters at Jackson, Mississippi.

The eighteenth annual meeting of the A. A. P. G. will be held at Houston, Texas, in March, 1933, at the invitation of the Houston Geological Society.

GROVER C. POTTER is doing consulting work in Beeville, Texas. His address is Box 1177.

R. E. SHERRILL is on leave of absence for one year from the University of Pittsburgh to do research work and study at Cornell University, Ithaca, New York.

EVERETT C. PARKER may be addressed at the Continental Oil Company, Geological Department, Ponca City, Oklahoma.

The annual fall meeting of the Pacific Section of the Association will be held at the Biltmore Hotel in Los Angeles, November 3 and 4. FRANK A. MORGAN, Rio Grande Oil Company, 855 Subway Terminal Building, Los Angeles, is in charge of the program.

WAYNE C. RAUCH has been employed by the Superior Oil Company of California, with headquarters at Dallas, Texas.

E. DeGolyer has recently been elected president of the Montclair Society of Engineers (New Jersey), a local organization including 350 engineers of all classes.

Harold C. Culver, State College of Washington, Pullman, has an article in the September, 1932, issue of *Petroleum World* entitled "What the Facts Reveal of Washington's Prospects for Oil Development."

George I. Adams, head of the department of geology in the University of Alabama, died on September 8, at the age of 61 years.